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The Organic and Mental Effects of repeated Bodily Rotation

THE ORGANIC AND MENTAL EFFECTS OF REPEATED BODILY ROTATION

BY

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Coleman Roberts Griffith

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THE ORGANIC EFFECTS

CHAPTER I

INTRODUCTION

It has been frequently observed that a rapid spin upon the heel or a few turns on a merry-go-round may lead to a confused and uncomfortable state of mind and to an uncertain control of the body. So sensitive is the organism to disturbances of this kind that a quick jerk of the head to the right and to the left is often sufficient to induce a momentary giddiness; while under more violent conditions, the effects may be severe and widespread.

A. HISTORICAL SETTING. Scientific interest in the nature and the causes of dizziness and of the concomitant loss of bodily control goes back almost a hundred years.[1] About that time the discovery was made by Flourens[2] that this kind of disturbance could be induced by exciting certain portions of the ear or by surgical insults of one kind and another to the cerebellum and to other central structures. The facts of dizziness had already been admirably described by Erasmus Darwin[3] and Purkinje;[4] and the relation of the

1. A survey of the principal work already done on the structure and functions of the semicircular canals, together with a more detailed account of the history of the psychological problem, is soon to appear.
2. Flourens, P., Recherches expérimentales sur les propriétés et les fonctions du système nerveux. Bailliere, Paris, 1842, pp. 438-501.
3. Darwin, E., Zoönomia, the laws of organic life, 1795. 3rd. ed., 1801, pp. 327-356.
4. Purkinje, J., Mitteilungen über Scheinbewegungen und über den Schwindel, Bull. d. naturw. Sektion d. Schles. Gesellsch. f. vàterland. Kultur, 1825-26, 10. Reprinted in Aubert's Studien über die Orientierung, Tübingen, 1888.

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ear to these facts raised a good deal of discussion, for it had been commonly supposed that the ear was concerned with hearing alone. But experimental evidence soon made it clear that a part of the internal ear was not in any way connected with the mediation of auditory qualities, and with this demonstration a new group of problems was proposed to experimental physiology and psychology. It was first necessary clearly to establish the precise relation obtaining between the excitation of the internal ear and the effects incident to a disturbed balance. As a result of the painstaking work of a large number of investigators this relation was established in such a manner as to bring about the discovery of a new end-organ in the semicircular canals, viz., the hair cells in the ampullae. With this discovery, investigators went on to describe the mode of excitation of the new end-organ, to delineate its central connections, and to analyze the effects produced by its excitation. Amazing progress was made in spite of theorists who from time to time insisted that the canals were the end-organs for the appreciation of time and space, or for noise, or for apprehending the direction of sound. By the year 1900, three hundred experimental investigations and more had accumulated a considerable body of doctrine about the canals and their functions. For example, it was maintained that the inertia of the liquid within the membranous labyrinth or even the inertia of the whole membranous structures provided the adequate stimulus for the vestibular end-organs. The excitation initiated was supposed to set up through the central connections of the vestibular nerve, i.e., the vestibular nucleus and the cerebellum, all kinds of equilibratory adjustments. Some of these were no more than variations in tonic effect (Ewald), while many other investigators insisted that the adjustments were more positive, taking the form of movements compensatory to bodily displacement. In short, a great amount of circumstantial evidence had been accumulated going to show that the end-organs in the semicircular canals were end-organs concerned chiefly in the

maintenance of equilibrium. Furthermore, it had come to be commonly accepted that balance or the maintenance of position was reflexly carried out by excitations from these end-organs.

Now chief,-because regular in appearance and easy of control,-among the movements excited by the stimulation of the semicircular canals are certain ocular movements known as "nystagmus." In fact, these ocular movements are so constant in their appearance as to have won for themselves the designation of "simple reflexes." It is upon these movements that most of the recent work has been done, the shift in point of interest occurring in the following manner. About 1906 Robert Bárány of Vienna recognized the clinical significance of such a close relation between the ear and the eyes and he immediately began, therefore, to make a clinical use of the great amount of work that had been done on the canals.[1] And thus, as is common in the history of the sciences, attention shifted from the question as purely academic to the practical application of the facts already at hand. It was Bárány's hope to use the ocular effects of vestibular stimulation as an index to the functional integrity of the neural paths involved, especially of the paths lying within the cerebellum itself. One of the contemporary scientific problems is, therefore, directed toward the nature of the ocular effects of stimulation of the canals. In this connection, it is significant to note that almost, if not all, of the evidence for the function of the canals rests upon unrepeated excitations of various parts of the mechanisms concerned. That is to say, the stimulation of the end-organs in the semicircular canals results immediately in a complex group of organic and mental effects. Certain of these effects, and especially the ocular movements, regarded as reflex, have been put to important use in the clinical laboratory. No consistent account has been taken of the effect of

1. Bárány, R., Untersuchungen über den vom Vestibularapparate des Ohres reflektorisch ausgelösten rhythmischen Nystagmus und seine Begleiterscheinungen, Monat. f. Ohrenhk., 1906, 40, 193-297.

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continued excitation, either upon the ocular movements or upon the rest of the body.

B. STATEMENT OF PROBLEM. The problem of this investigation, therefore, is to describe the organic effects of repeated bodily rotation. It was observed by many of the earlier investigators that, when the vestibular branch of the VIIIth nerve was cut, or one or more of the canals injured, the compensatory movements either of the eyes or of the head and the changes in posture were at first intense but gradually disappeared within a few days. It is strange that this fact did not suggest that continued or repeated excitation of the end-organs in the canals would lead to a profound modification in the effects usually produced. As a matter of fact, however, we have failed to find an instance where a consistent effort has been made to repeat ampullar stimulation in the same organism a great number of times. This failure is partially due, no doubt, to the fact that almost all of the earlier work on the subject involved surgical means of excitation, a method which naturally excludes extensive repetition. Furthermore, the immediate effects are so complicated and then appear in such different forms in different organisms that clear thinking and a community of opinion have been almost impossible. We shall, therefore, undertake to excite the vestibular end-organs in the human subject a large number of times in succession and seek then to describe the organic effects issuing from this repeated stimulation.

C. DISCUSSION OF METHODS. Various methods are used in the clinical laboratory for the arousal of vestibular activity. The method of rotation was first used by Purkinje, and almost every investigator since his time has used it in one form or another. Bárány adapted it, as well as other methods, to the clinical laboratory. The method of rotation commends itself as preferable to other methods by the ease with which it can be controlled and also by reason of its adaptability. The galvanic method has likewise had

a long history. Purkinje,[1] Rémak,[2] Brenner,[3] Hitzig,[4] Kny,[5] Breuer,[6] Jensen,[7] and many others used it for the excitation of "vestibular sensations." Of these investigators, Hitzig was the first to give a clear and accurate account of "galvanic vertigo." Jones[8] describes the recent use of the galvanic method; but the method has not been found so practicable as other methods. The thermal or caloric method has had a similar history. Goltz[9] said in 1870 that the effects of the use of hot and cold water had become common knowledge by that time. Hitzig,[10] Breuer,[11] and Bornhardt[12] have used the caloric method extensively. In case the tympanic membrane is broken, it is possible to excite the canals by pressure. After describing the methods we are discussing, Alexander[13] laid claim to the first use of the method of pressure; but Bárány[14] says that several investigators had observed the effects of pressure before Alexander. Mechanical stimulation with needles and by cutting as well as chemical stimulation have frequently been resorted to. Spamer[15] used all of these

1. Purkinje, J., Ueber die physiologische Bedeutung des Schwindels und die Beziehung derselben zu den neuesten Versuchen über die Hirnfunction, Rust's Mag. f. d. ges. Heilk., 1827, 23, 284-310.
2. Rémak, R., Galvanotherapie der Nerven und Muskelkrankheiten, Berlin, 1858.
3. Brenner, R., Untersuchungen und Beobachtungen auf dem Gebiete des Elektrotherapie, Leipzig, 1868, I, 75ff; II, 30ff.
4. Hitzig, E., Ueber die beim Galvanisieren des Kopfes einstehenden Störungen der Muskelinnervation, etc., Arch. f. Anat. u. Physiol., 1871, 716-772.
5. Kny, E., Untersuchungen über den Galvanischen Schwindel, Arch. f. Psychiat., 1887, 18, 637-658.
6. Breuer, J., Neue Versuche an den Ohrbogengängen, Pflüger's Arch. f. d. ges. Physiol., 1888, 44, 87-156.
7. Jensen, P., Ueber den galvanischen Schwindel, Pflüger's Arch. f. d. ges. Physiol., 1896, 64, 182-222.
8. Jones, I.H., Equilibrium and Vertigo, 1918, pp. 247ff.
9. Goltz, F., Ueber die physiologische Bedeutung der Bogengänge des Ohrlabyrinths, Pflüger's Arch. f. d. ges. Physiol., 1870, 3, 172-192.
10. Hitzig, E., op. cit.
11. Breuer, J., op. cit.
12. Bornhardt, A., Experimentelle Beiträge zur Physiologie der Bogengänge des Ohrlabyrinths, Pflüger's Arch. f. d. ges. Physiol., 1876, 12, 471-521.
13. Alexander, G., Die Funktion des Vestibularapparates, Bericht u. d. IV. Kongress f. exper. Psychol., 1911, 74-94.
14. Bárány, R., see Alexander, G., op. cit. p. 91.
15. Spamer, C., Experimenteller und kritischer Beitrag zur Physiologie des halbzirkelförmigen Kanäle, Pflüger's Arch. f. d. ges. Physiol., 1880, 21, 479-590.

methods with keen critical ability. From this account, it is apparent, therefore, that Bárány's sole contribution to method has been the adaptation of these historical methods to the clinical laboratory.

CHAPTER II

THE EXPERIMENTS

A. THE METHOD OF PERIODIC ROTATION. Of the various means of exciting the canals which we have just discussed, we shall be concerned alone with the method of rotation. We shall, moreover, insist that the periodic use of this method is opposed in spirit and in practice to the method of single excitations and to observations of the immediate effects of such excitations. We shall find that the use of the method throws an entirely different light on certain present conceptions of the nature both of the organic and of the mental effects of amullar stimulation. In our experiments, each subject was given a rotation-series once a day (Sundays and a few unavoidable lapses excepted), a series comprising five trials to the right and five to the left given alternately (*i.e.*, one trial to the right and then one to the left, and so on) and each trial consisting of ten revolutions. For the most part, one minute's rest was given between trials, with three minutes between every five trials. Three or four subjects were used simultaneously, the series being continued in each case so long as the subject was available.

B. THE GENERAL PROCEDURE. For the purposes of our experiments, a modified Bárány rotation chair was used. This chair, which is described by

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Jones,[1] has suffered certain American modifications but these are of doubtful value for research. The chair used in our experiments was especially designed for research by Professor Bentley. In the first place, the chair was so constructed as to enable the operator to stop it gradually by a friction-brake rather than suddenly as in certain clinical models. The reason for and significance of this provision will presently appear. The chair was also insulated and wired in such a manner that the observer could graphically register, by the pressure of a key placed in his hand, either during or after rotation, any time intervals or events which he might be instructed to note and to record. In addition, contact points were adjusted at intervals of 90 degrees about the base of the chair so that its rate of revolution could be indicated on the smoked drum. By comparing the records from these contact points with the records from a second's pendulum, it was possible to find that the chair was rotated with an average mean variation of less than one-tenth of a second per revolution.[2] By means of two projections,one in front and one at the back, an almost continuous impulsion was given to the chair. In this way, jarring and irregularities in the rate of rotation were so far reduced that observers repeatedly described the motion as similar to that of a well balanced object along a smooth and oily surface.[3] A click from the second's pendulum and the visual cue from its swing gave to the experimenter a wholly dependable kinaesthetic and visual rhythm, making it possible to start and to stop the chair and to maintain its speed with a negligible degree of variation. The records of the smoked drum indicated that the chair attained full speed at the

1. Jones, I.H., op. cit., pp. 233ff.
2. Dunlap asserts that the variation in the clinical laboratory has been as great as 13-27 sec. when a 20 sec. period was prescribed. See Amer. Med. Ass., 1919, 73, 54.
3. Absolute control of the rotation is vital if constancy is to be expected. The otologists have quite overlooked this factor, as is betrayed by the unevenness of the rotation and the abrupt stop. Several observers in this investigation who have taken the otological examination for Army Aviation

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end of one second, the mean variation of error being less than one tenth of one percent. The regular rate of rotation,-one turn in two seconds for ten turns,-was then maintained until the stop, which was accomplished evenly and with a mean variation of approximately one ninth of one per cent of error. A push-button connected with a magnetic signal marker enabled the experimenter to register on the smoked drum the number of eye-movements made after the chair came to rest. In a similar way was registered the time at which all apparent movement in the observer's visual field ceased. Two kinds of apparent movement in the visual field follow rotation. (1) An easily recognized jerky movement of objects, which is a function of the eye-movements described above, is followed (2) by a 'flowing' in the visual field which persists for several seconds. The visual field then clears up, save for whatever after-images may have been induced by the prolonged period of fixation. The disappearance of the jerky movements was alone considered in making our reports.

As regards the registration of the number of eye-movements, the following procedure was adopted. As Appunn lamella used for practice purposes served also to determine the accuracy of the experimenter in counting the number of eye-movements. Vibrations-rates up to seven a second were accurately counted, and by counting every other vibration of the lamella, the experimenter was able to record with accuracy rates up to twelve in the second, and considerably beyond with a small calculable error. The eye-movements are easier to record than are the vibrations of the lamella, and, moreover, within the group of observers here reported, none showed an original rapidity of movement greater than five in the second. There were thus three values obtained from each subject as the series proceeded; (1) the record from the subject himself of the cessation of apparent movement of objects, (2) the record of the

declare that the rotation here given was far better controlled than that given during the official tests.

eye-movements made, and (3) of the duration of the after-nystagmus. Measurements of the amplitude of the movements were made with the aid of a reading microscope.

The method of treating these records can be seen in Table I, which is chosen at random from the original records. The Table represents a

TABLE I

Rotation to Right

Trial	Time	m.v.	No.	m.v.	App.Mvt.	m.v.
1	19.0	2.8	38.0	1.6	19.0	2.6
2	16.0	0.2	39.0	2.6	17.0	0.6
3	16.0	0.2	37.0	0.6	16.0	0.4
4	17.0	0.8	34.0	2.4	16.0	0.4
5	13.0	3.2	34.0	2.4	14.0	2.4
Average	16.2	1.44	36.4	1.92	16.4	1.28
			Rotation to Left			
1	20.0	3.4	39.0	2.8	22.0	1.8
2	18.0	1.4	39.0	2.8	18.0	0.8
3	16.0	0.6	37.0	0.8	17.0	0.2
4	15.0	1.6	35.0	1.2	15.0	2.2
5	14.0	2.6	31.0	5.2	14.0	3.2
Average	16.6	1.92	36.2	2.56	17.2	2.24
Aver. of R & L	16.4	1.68	36.3	2.24	16.8	1.76

single day's rotation period of ten turns, five to the right and five to the left, done alternately. It can be seen that for a decreasing group of measures the m.v.'s are relatively small. The regularity with which the first measures exceed and the last measures fall short of the average indicates throughout the investigation the regularity with which the decrease takes place. That is to say, these mean variations are, for the most part, an index of the regularity of decrease in the measures averaged and are not a true measure,-as the m.v. should be,-of reliability.

A fixation point was provided on a large black background upon which were placed vertical white strips 12 mm. wide and 25 mm. apart. The

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fixation point was a small cross in the center of the field set on one of the strips of white and was 1 m. from the eyes of the subject. These vertical strips enabled the subject to indicate the cessation of apparent movement with much more ease and accuracy than he could have done with the otologist's indefinite fixation outside a window.[1] The position of each observer was held constant by a rod adjusted to the side of the chair in such a way that it stood at an angle of 30 degrees from the vertical. The head of the individual was then placed in such a position,-by the use of an improved head-rest,- that a line connecting the middle of the shoulder with the middle of the ear was parallel with the rod. It was thus made certain that the head of the subject was always in such a constant position that the horizontal canals were approximately parallel with the floor and at right angles to the axis of rotation. After the 'ready' signal and at the 'now' signal, the subject was turned ten times in twenty seconds[2] and stopped by means of the brake so that a line on the foot-rest of the chair exactly coincided with a line placed on the floor. After a little practice, the experimenter found that this could be accomplished with an average error of less than 2 cm.

1. As a matter of fact, we shall show in a later paper that fixation is an important item in the conditions that govern the appearance of the organic as well as the mental effects of rotation. Fixation at some point out of a window as used by the otologists in the official tests of the Army Air Service, e.g., is extremely inaccurate and undependable.
2. There is nothing sacred about this rate of rotation, although some of the otologists seem so to regard it. The appearance of the effects of rotation is directly proportional to the rate and the number of turns. That is to say, one revolution at any ordinary speed will not, as a rule, produce nystagmus, but two turns may. The amount of nystagmus then increases as the number of turns increases. The ratio has not been established and neither have the limits; although it is known that the duration of the after-nystagmus increases with a constant rate of rotation (1 rev. in 2 sec.) up to fifteen turns. Bárány found that the after-nystagmus suffers decided change in kind when the number of rotations is made as high as sixty. Ocular and other organic effects generally appear in an unpracticed individual after two complete turns. The speed of ten rotations in 20 sec. was chosen partly because it admitted adequate comparison of the results with those of other investigators and partly because the effects aroused are of sufficient intensity to furnish conditions suitable for observation and description.

C. THE SUBJECTS. The subjects used during these experiments were chosen at random from the various courses in psychology and were for the most part upper-classmen.[1] Before using them in the experiments, they were given the usual turning tests for 'vestibular normality.' That is to say, the clinical laboratory has been working on the assumption that if the ocular movements following rotation persist for an average time of 25 sec., in so far forth, the subject is 'normal.' Usually, however, further tests are given such as the 'past-pointing' tests and the 'falling' tests. Both of these tests depend upon systemic innervations from the end-organs in the canals. (See Jones, I.H., Equilibrium and Vertigo, 1918, passim.) An otologist who had been selected by the Surgeon General's Office to give tests to candidates for the Air Service, pronounced all our subjects 'normal' after having reviewed our results and administered some of the tests himself. That is to say, our subjects gave an average after-nystagmus of from twenty to thirty seconds; they past-pointed to the right and to the left on an average of two or three times; and finally, they fell to the right and to the left in a pronounced manner.

1. The writer wishes to acknowledge his appreciation of the services of all the subjects who willingly submitted themselves to the trying conditions of the experiment. The names follow: V.B. Adams, H.C. Burleson, J.W. Cannon, L.K. Ceceil, S.M. Dietrich, A.R. Elliott, W.H. Griffith, D.T. Harris, H.O. Hope, S.C. Nag, L.R. Raines, W.H. Rayner, J.A. Sanders, A.D. Sinden, H.M. VanDoren, R.W. Wuestermann. H.C. Burleson acted as experimenter while the writer was a subject. The writer wishes also to express his sincere appreciation of the aid and counsel of Professor M. Bentley, under whose direction and criticism this investigation was undertaken and carried through.

CHAPTER III

THE ORGANIC RESULTS OF ROTATION

Under the experimental conditions just described, there is produced, both during and after rotation, an elaborate array of organic and mental effects. In the naive subject all of these effects are usually of great severity and complexity. Occasionally they become overwhelming, as in nausea.[1]

A. LOCAL EFFECTS: NYSTAGMUS. All of the organic effects have commonly been assigned, without much criticism or analysis, to two gross classes. As we have just seen, the unfailing regularity with which the ocular effects appear has earned for them a separate place. These effects, which are sometimes called 'vestibular nystagmus', are characteristic. As rotation begins, the eye tends to lag behind the movement of the head, and then suddenly to recover its original position, only to lag behind again, and so on. After the cessation of the rotatory movement, the order of the ocular deflections is just reversed. The slow phase, which took place in the direction opposite to the original rotation, now takes place in the direction of the bodily movement. The quick phase, which previously took the direction of rotation, now runs in the contrary direction. In case the head is bent forward or to the side, the movement is circular but of the same general kind. We are here concerned only with the horizontal movements aroused by rotation about an axis lying in or near the head. Furthermore, the ocular effects will make up the bulk of our experimental evidence on the nature of the organic effects of rotation, and we shall be primarily concerned with the movements occurring after the cessation

1. During the course of our experiments three subjects were obliged to discontinue the series temporarily, on the first day, because of nausea. In one case only, however, did vomiting take place. Almost all the subjects were slightly nauseated on the first day but rarely on the second. As has been frequently noted, all of the organic effects are tremendously increased in intensity if the axis of position is changed at any time during rotation

of rotation.

B. SYSTEMIC EFFECTS: MUSCULAR INNERVATIONS: VISCERAL AND VASCULAR CHANGES. The other organic effects which have come to occupy a prominent place are certain innervations of the limbs and of the body as a whole due to a diffuse involvement of the whole skeletal musculature. If the limbs or the head are held free from support, they tend to move in a charactersitic manner. The head may turn to one side or to the other, depending upon the direction of bodily rotation, and the limbs on the side of the body toward the rotation tend to move in the same direction. Furthermore, the possibility of nausea, of excessive perspiration, and the 'feel' of internal changes in the viscera, the lungs and the head suggest that the excitation of the canals has a direct influence on many of the internal organs and upon the sympathetic system.

Aside from these general organic effects, which we shall consider in a secondary way only, there is a large class of effects that are commonly dismissed as 'mental.' They are usually spoken of as 'vertigo,' 'dizziness,' and nausea. As a matter of fact, analysis reveals a host of kinaesthetic sensations localized less clearly about the trunk and the limbs than about the neck, the face, and especially the eyes. The trained observer discovers a background of organic processes which seem finally to become localized about the lower end of the esophagus. Visceral coolness and pressure, clearer than the other processes, are occasionally accompanied by a bad taste in the mouth, an ecessive flow of saliva, hints of a disagreeable olfactory quality, and a diffuse 'feel' of peripheral warmth; and the culmination of the whole experience may come in the form of kinaesthetic pulls and tensions throughout the viscera and abdominal walls,-the processes characteristic of nausea and re-

or during the persistence of the after-nystagmus. One subject (O) responded to the falling test by repeated clonic contractions of the lower limbs.

versed peristalsis. In a subsequent investigation we shall undertake in a serious manner to analyze these residues of rotation and to point out their relation to the whole experience of rotation.

CHAPTER IV

PHYSICAL AND PHYSIOLOGICAL FACTORS WHICH MODIFY THE ORGANIC RESULTS OF ROTATION

We come now to the central part of our experimental enquiry. The whole course of the investigation goes to show that nystagmus is only a small part of the total organic effect of rotation[1] and that all of the effects, both local and systemic, tend to decrease in complexity and in intensity and finally to disappear under the influence of prolonged turning. That is to say, our investigation shows that these effects can be profoundly modified in their appearance by certain physical and physiological factors which we shall describe immediately.

A. MODIFICATION BY PERIODIC REPETITION. Of the progressive changes occurring on the organic side, the most outstanding is the decrease from day to day and the decrease within a single diurnal series of the duration of the after-nystagmus, of the number and the amplitude of the ocular movements, and finally, of the time of apparent movement in the visual field, due to periodic repetition. Tables II and III give, for each of 16 subjects, the averages for rotation alternately to the right and to the left in the successive

1. The otolgists have drawn a peculiar and curious distinction between nystagmus and the other effects of rotation, principally vertigo. For example, Jones (<u>op.cit</u>., p.5) says that "ear-stimulation produces certain definite phenomena--a rhythmic jerking of the eyes known as nystagmus, and a subjective sensation of turning which may be termed a systematized vertigo." We shall have occasion to discuss this distinction at another time. At present we must insist that the distinction is but a gross logical separation of the effects induced.

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Table II

Series	Subjects																											
	A	B	C	D	D con	E	F	F con.	F con.	F con.	G	G con.	G con.	G con.	H	H con.	I	J	K	K con.	L	L con.	M	M con.	N	O	P	P con
1	17.9	17.6	22.9	11.4	6.6	17.2	18.5	10.4	9.1	6.9	17.6	9.3	6.4	1.6	24.5	1.3	14.4	20.0	21.5	3.0	18.2	2.0	21.7	6.8	18.7	15.9	25.5	6.3
2	18.4	8.7	22.2	13.5	5.3	14.9	18.3	10.6	8.2	6.0	16.4	8.4	5.4	1.0	19.6	0.0	15.0	14.5	21.5	3.8	16.5	3.0	18.7	9.6	18.2	7.3	27.0	5.1
3	17.2	6.4	21.9	12.3	6.8	14.7	16.4	10.4	10.3	6.9	15.5	8.5	5.5	1.0	16.6	0.0	13.8	17.7	22.4	2.9	12.0	1.6	16.4	10.1	16.7	6.0	25.2	5.4
4	14.6	6.4	23.7	14.7	6.3	12.0	13.5	10.0	7.9	6.3	14.0	8.5	5.4	0.7	13.5	0.0	12.1	12.1	17.1	2.6	15.1	2.1	15.3	6.1	15.6	3.3	22.3	5.3
5	13.0	4.8	21.9	15.5	7.4	10.5	14.8	11.1	9.8	6.4	13.5	8.9	5.4	0.2	11.8		14.0	11.8	16.2	2.1	12.5	0.6	15.5	4.9	14.8	1.9	18.3	5.7
Av.	15.8	8.8	22.5	14.7	5.3	13.9	16.3	10.5	9.1	6.5	15.4	8.7	5.6	0.9	17.2		13.9	15.2	19.7	2.9	14.8	1.8	17.5	7.5	16.8	6.9	23.7	5.6
6	9.6	4.6	19.4	13.1	7.5	8.5	13.5	9.5	9.0	5.6	12.6	9.1	4.7	0.0	10.4		12.1	10.4	15.3	2.4	11.3	0.0	14.3		13.9	1.5	16.8	4.7
7	8.0	2.5	18.5	12.9	4.6	8.7	12.4	10.4	9.5	6.3	10.8	8.5	5.0	0.0	8.6		12.6	11.1	14.2	1.8	11.5	0.0	18.1		13.5	1.2	16.9	4.1
8	7.3	3.1	18.6	12.0	5.8	7.2	11.4	10.1	8.1	5.4	10.0	8.9	4.3	0.0	9.1		11.1	11.4	12.4	1.2	10.5		12.3		13.3	1.5	14.2	4.2
9	8.8	2.3	20.4	9.4	3.8	7.6	11.3	10.7	8.3	6.1	10.7	8.4	5.0		7.5		10.7	11.8	11.3	0.0	9.2		11.3		10.3	0.1	13.2	3.6
10	8.5		17.2	8.2	3.0	6.4	13.6	9.7	7.6	5.0	11.4	7.9	4.0		8.3		10.0	11.4	10.2	0.0	9.0		10.1		11.9	0.0	11.9	3.5
Av.	8.4	3.1	18.8	11.1	4.9	7.7	12.4	10.1	8.5	5.7	11.1	8.4	4.6		8.8		11.3	11.2	12.7	1.1	10.3		13.2		12.6	0.8	14.6	4.0
11	7.3		18.2	8.4		6.5	11.5	9.1	8.4	6.1	11.1	7.3	3.6		7.1		12.5	11.0	11.1		7.9		11.1		9.4	0.0	10.5	3.7
12	6.7		18.9	8.8		5.7	11.4	9.6	7.4	5.4	10.3	7.7	2.8		7.6		10.6	10.9	9.5		7.2		8.5		9.5		11.8	2.5
13	6.2		17.9	9.1		6.9	10.7	9.9	8.3	5.5	11.4	7.7	3.8		6.7		9.7		9.0		6.4		11.6		9.6		11.2	1.0
14	4.8		15.9	7.8		5.3	11.5	9.2	7.3	4.8	10.4	8.0	2.8		5.6		9.9		7.2		5.2		7.3		8.9		7.3	0.0
15	3.8		14.6	7.0		5.3	9.8	9.4	7.8	5.1	10.1	8.8	3.3		4.7		10.2		7.3		5.3		9.1		7.8		7.3	0.0
Av.	5.5		17.0	8.2		5.9	11.0	9.4	7.8	5.3	10.6	7.9	3.2		6.3		10.6	10.9	8.8		6.4		9.5		9.0		9.6	1.4
16				5.1		2.9	10.9	8.8	6.5	6.3	10.2	7.1	2.8		4.2				7.3		4.1		6.9		8.7		8.7	
17				6.1		3.4	9.8	9.0	7.0	4.8	10.8	7.7	2.3		4.1				5.5		3.6		8.9		6.9		7.5	
18				6.7		2.6	10.4	8.9	6.8	4.1	10.0	5.8	2.2		3.7				5.6		2.9		5.8				5.5	
19				6.0		2.2	9.3	9.7	7.2	4.5	9.8	5.7	2.3		3.5				5.3		3.1		6.4				6.7	
20				5.6		0.0	9.4	8.4	6.2	4.0	8.9	5.5	2.0		2.6				3.6		2.8		6.3				6.5	
Av				5.9		2.1	10.0	9.0	6.7	4.7	9.9	6.4	2.3		3.6				5.4		3.3		6.8		7.8		7.0	
Sec. Decrease	14.1	15.3	8.3		13.4	17.2				14.5				17.6		24.5	4.2	9.1		21.5		18.2		16.8	11.8	15.9		25.5
% Decrease	80	87	47		81	100				84				100		100	29	45		100		100		77	63	100		100
Rate of Decrease	.94	1.70	.55		.45	.82				.18				.27		1.11	.28	.75		.77		.73		.67	.70	1.59		.78

Table II showing average time of after-nystagmus from ten rotations (5 to R and 5 to L) of ten revolutions each, for sixteen subjects (A-P).

Series	A	B	C	D	D con.	E	F	F con.	F con.	F con.	G	G con.	G con.	G con.	H	H con.	I	J	K	K con.	L	L con.	M	M con.	N	O	P	P con.
1	15.5	10.9	36.5	8.2	5.8	20.2	39.0	18.7	18.3	9.5	34.5	15.2	7.4	1.8	56.1	1.5	20.8	47.9	32.5	3.3	26.5	2.9	35.2	5.3	35.0	10.8	47.5	5.2
2	20.3	4.3	40.5	5.5	4.6	22.6	39.5	15.4	12.9	6.7	31.2	12.9	6.3	1.2	51.3	0.0	25.4	26.8	30.4	5.1	28.0	3.6	30.7	11.0	30.2	8.1	37.0	4.5
3	18.0	2.3	38.8	5.1	5.9	16.3	36.3	19.3	18.0	9.1	31.0	13.1	6.5	1.2	38.7	0.0	20.6	39.9	40.4	3.3	18.6	1.9	24.9	11.2	35.2	5.8	40.2	4.7
4	14.1	2.6	39.9	5.9	4.6	13.0	30.7	15.0	11.0	7.6	26.6	11.9	5.4	0.7	31.2	0.0	24.6	25.3	30.5	2.9	28.4	2.5	25.6	6.9	27.5	4.0	35.8	4.7
5	11.9	4.0	40.8	7.2	5.9	11.0	33.1	18.9	15.1	8.2	26.9	13.4	6.2	0.2	27.2		25.6	29.1	29.5	2.0	20.6	0.5	25.9	5.2	25.3	2.0	27.0	4.4
Av.	15.9	4.8	39.3	6.4	5.7	16.7	35.7	17.5	15.1	8.1	30.0	13.3	6.4	1.0	40.9		23.4	33.8	32.6	3.3	24.4	2.3	28.4	7.9	30.6	6.1	37.5	4.7
6	7.9	2.6	34.9	5.2	6.9	9.5	30.6	15.2	11.2	6.6	25.0	13.3	5.2	0.0	22.9		26.6	24.6	24.0	2.4	21.0	0.0	23.7		24.8	1.7	25.2	4.0
7	5.0	2.1	34.7	6.3	3.1	9.9	27.5	16.8	13.6	8.0	19.9	11.4	5.2	0.0	18.5		25.2	22.3	20.0	1.8	19.1	0.0	28.1		20.8	1.6	20.5	3.6
8	4.5	3.3	37.4	6.1	5.1	7.9	24.5	17.2	10.5	7.3	17.4	12.8	4.3		16.6		21.8	26.1	20.9	1.3	19.0		17.3		20.7	1.4	19.1	3.2
9	9.9	2.8	37.4	4.5	2.6	7.7	27.2	17.9	12.3	8.2	18.1	12.0	5.2		11.4		22.0	30.7	19.1	0.0	16.9		14.5		17.7	0.1	18.2	3.3
10	8.4		30.5	3.8	1.9	5.2	32.1	14.2	10.7	7.2	20.0	11.6	3.8		12.1		18.4	27.4	17.2	0.0	15.4		13.7		16.1	0.0	16.3	2.6
Av	7.1	2.7	35.0	5.2	3.9	8.0	28.4	16.3	11.7		20.1	12.2	4.7		16.3		22.8	26.0	20.2	1.1	18.3		19.4		20.0	1.0	19.8	3.3
11	8.2		33.3	3.5		6.5	26.7	13.6	13.8	7.9	18.1	10.9	3.7		12.0		25.0	26.2	15.5		12.3		15.7		14.7	0.0	12.6	2.6
12	7.9		33.4	3.7		5.1	28.6	12.6	9.8	6.4	17.5	10.9	2.8		10.6		18.4	22.3	14.0		11.5		11.6		13.7		15.5	2.0
13	5.1		32.4	3.6		6.1	24.9	16.6	13.4	6.2	19.2	11.0	4.0		9.6		16.0		13.1		10.6		18.0		13.4		10.9	0.5
14	4.9		30.4	6.1		4.2	29.8	14.2	9.3	6.2	17.9	11.7	3.0		7.0		18.0		9.1		7.7		11.4		12.2		5.2	0.0
15	3.6		29.5	3.5		4.8	20.4	16.4	12.8	6.8	17.1	11.7	3.3		6.2		15.2		9.2		7.8		11.6		11.4		5.5	0.0
Av	5.9		31.8	4.1		5.4	26.1	14.7	11.8		18.0	11.2	3.4		9.0		18.5	24.2	12.2		10.0		13.6		13.1		9.9	0
16				3.8		2.9	25.0	13.3	8.3	6.9	17.7	11.1	2.9		5.3				10.6		5.5		9.7		13.6		7.0	
17				5.0		3.1	20.3	14.8	11.3	5.2	18.6	10.2	2.5		4.3				7.2		5.2		11.0		9.9		5.4	
18				5.5		2.7	22.8	10.6	8.9	4.8	17.3	7.5	2.3		4.1				6.2		4.8		7.2				4.6	
19				4.7		1.9	15.7	14.3	11.1	6.0	18.3	7.2	2.2		3.7				8.1		4.7		8.0				5.7	
20				4.7		0.0	17.8	11.1	7.9	4.0	14.5	7.8	1.9		2.8				4.4		3.7		7.4				6.2	
Av				4.7		2.2	20.3	12.8	9.5		17.3	8.7	2.4		4.0				7.3		4.8		8.6		11.7		5.8	
Decrease sec	11.9	8.1	7.0		6.3	20.2				35.0				34.5		56.1	5.6	25.6		32.5		26.5		30.0	25.1	10.8		47.5
Decrease %	76	74	19		77	100				90				100		100	27	53		100		100		85	72	100		100
Rate of Decrease	.79	.90	.47		.02	.92				.37				.51		26.2	.37	2.13		1.17		1.06		1.20	1.48	1.20		1.40

Table III showing average number of ocular movements from ten rotations (5 to R and 5 to L) of ten revolutions each, for sixteen subjects (A-P).

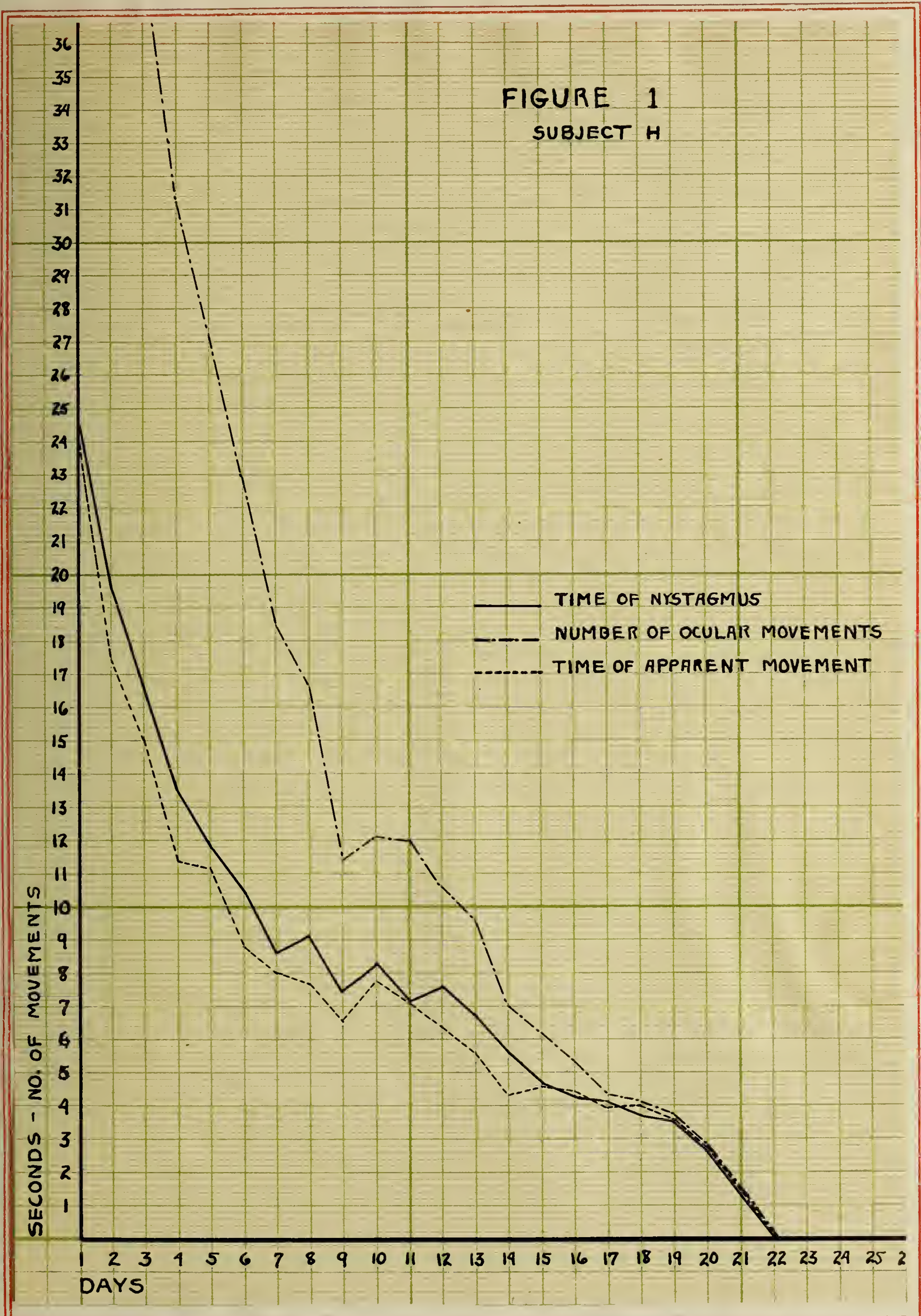
FIGURE 1
SUBJECT H
TIME OF NYSTAGMUS
NUMBER OF OCULAR MOVEMENTS
TIME OF APPARENT MOVEMENT
SECONDS - NO. OF MOVEMENTS
DAYS

daily series. Figure 1 is a typical curve based on the results obtained from subject H.

When Tables II and III and Figure 1 are carefully scrutinized the following facts appear:

(a) Every observer shows more or less decrease in the duration of nystagmus, in the number of ocular movements, and in the time of apparent movement.[1] It will be observed that the three representative values decrease together. The decrease in duration of nystagmus varies from 29 % in the case of subject I, to 100 % for subject E, G, H, K, L, O and P. The average amount of decrease for all subjects in these tables in seen to be 79 % or more than three fourths of the initial time. Furthermore, there is every reason to believe that had the other series been continued sufficiently, all subjects would have decreased 100 %. The decrease in the number of movements varies from 19 % for subject C to 100 % for subjects E, G, H, K, L, O and P, or again,an average of 79 %. The same ratio holds true also for the duration of the apparent movement in the visual field.

(b) There is a wide individual difference in the initial values. Subject I gave an average nystagmus time for the first ten trials of 14.4 sec. while subject P gave 25.5 sec. It will be observed that most of these initial values are below those given by the otologists as constituting 'normality'. It will be recalled that this 'normality' value was about 25 sec. As a matter of fact, the average of all our subjects for the first ten trials is but 18.0 sec. This one comparison is an outstanding example of the sensitivity of the ocular responses to repetition. The low average found in

1. As can be seen from Figure 1, the line showing the time of apparent movement almost conincides with the line showing the time of nystagmus. That is to say, a table similar to Tables II and III, but giving the times of the apparent movement of objects in the visual field would almost duplicate Table II and we have not, therefore, included such a table.

[illegible]

our case is due to the fact that our initial values are an average of the first ten rotations of ten revolutions each. Within these ten rotations the decrease is already so great as appreciably to lower the average time of nystagmus. By referring to Table IV we get a more detailed analysis of the first ten trials for our sixteen subjects. It will be seen from this table that the initial nystagmus times were R 22.5 and L 23.4, values which fall close to the median assumed by otologists to be "normal".[1] The striking fact, however, is the decrease within the first few minutes of rotation, a decrease which is obviously due to the cumulative effect of repetition.

(c) The decrease in all the values is of a charactersitic kind. We have just pointed out the marked decrease within the first ten trials. Reference to any of the preceding tables or to the figure will show that a large part of the decrease takes place in the first few days. That is to say, there is a sudden drop in the curves which represent the temporal course of the nystagmus from day to day. We have found that all the subjects showed an average decrease of 79 % in the time of nystagmus. 57 % of this total amount takes place during the first half of a series, leaving the remaining 22 % to be

1. In view of otological practice, these standard or "normal" times should not be taken too seriously. In one list of about 1800 'official' examinations the duration of the after-nystagmus actually observed (omitting the extreme times) ran as follows (after one turn of 10 revolutions to the right):

Duration	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31 sec.
No.exam'd	32	70	41	137	24	<u>239</u>	49	137	102	137	146	158	54	66	27	98	10

The greatest number of cases for 'normal' men seems, then, to fall, not at 25 sec. or 26 sec., as we should expect, but at 20 sec. The table shows a striking distribution about 20 sec. and 30 sec. Possibly the otologist's watch has a preference for round numbers! If it has, it yields in a fair and openminded way at 26, the exact mean in the 'allowed' normal range of 16-36, and also at 16, the lowest permissible 'normal' for aviators. The sudden drop on either side of 16 sec. would seem to emphasize the high clinical importance of that number. The small number of 15-sec. cases would seem to suggest that Nature does her best, in a great human emergency, to follow the prescriptions and to exemplify the discoveries of her learned children.

			Subjects																
			A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Av.
Time of After-nystagmus	1st Trial	R	17.0	25.0	31.0	18.0	16.0	18.0	19.0	31.0	22.0	23.0	20.0	22.0	21.0	19.0	26.0	32.0	22.5
		L	22.0	20.0	23.0	24.0	20.0	27.0	17.0	25.0	23.0	29.0	24.0	20.0	26.0	22.0	22.0	30.0	23.4
	Av. 1st 10 Trials		17.9	17.6	22.9	16.4	17.2	18.5	17.6	24.5	15.4	20.0	21.5	18.2	21.7	18.7	15.9	25.5	18.1
	10th Trial	R	15.0	14.0	22.0	11.0	12.0	16.0	18.0	24.0	15.0	17.0	20.0	13.0	18.0	16.0	11.0	21.0	16.4
		L	17.0	14.0	19.0	24.0	16.0	16.0	16.0	20.0	13.0	18.0	20.0	18.0	14.0	17.0	8.0	21.0	16.8
No. of Ocular Movements	1st Trial	R	13.0	15.0	55.0	10.0	20.0	38.0	39.0	58.0	25.0	53.0	44.0	37.0	36.0	38.0	20.0	50.0	34.4
		L	24.0	12.0	42.0	12.0	21.0	46.0	35.0	50.0	23.0	71.0	41.0	25.0	44.0	31.0	18.0	52.0	34.2
	Av. 1st 10 Trials		15.5	10.9	36.5	8.2	20.2	39.0	34.5	52.1	20.8	47.9	37.5	26.5	35.2	35.0	10.8	47.5	30.1
	10th Trial	R	11.0	9.0	32.0	5.0	17.0	38.0	33.0	61.0	21.0	37.0	33.0	21.0	28.0	29.0	7.0	50.0	27.0
		L	15.0	8.0	30.0	10.0	18.0	35.0	25.0	51.0	18.0	45.0	31.0	27.0	24.0	29.0	7.0	38.0	25.6
Apparent Movements	1st Trial	R	17.0	20.0	—	17.0	16.0	20.0	19.0	30.0	22.0	25.0	20.0	23.0	20.0	19.0	26.0	32.0	21.7
		L	20.0	18.0	—	24.0	20.0	20.0	19.0	25.0	21.0	30.0	24.0	20.0	22.0	18.0	22.0	30.0	22.1
	Av. 1st 10 Trials		16.7	15.9	—	17.1	18.0	18.6	17.1	24.1	11.7	19.6	21.7	16.7	19.7	17.7	15.7	26.5	18.4
	10th Trials	R	15.0	14.0	—	12.0	14.0	16.0	18.0	24.0	13.0	16.0	20.0	9.0	17.0	16.0	11.0	24.0	16.7
		L	15.0	11.0	—	22.0	19.0	16.0	13.0	20.0	9.0	16.0	20.0	10.0	13.0	17.0	8.0	21.0	16.0

TABLE IV, showing, for each of 16 subjects, the time of after-nystagmus, the number of ocular movements, and the time of apparent movement of (a) the 1st trial to R and to L, (b) the average of the 1st 10 trials (5 R and 5 L), and (c) the last trial (10th) to R and L.

distributed over the last half of a series. Table V shows, in percentages,

TABLE V

Subjects	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Av.
% Decrease 1st half	55	72	19	54	63	50	56	71	35	50	66	60	63	41	90	70	57

this decrease during the first half of all the series of the sixteen subjects. These figures are more significant than at first appears. Only a few of the series were carried to completion, i.e., to zero. On this account, the distribution of the amount of decrease cannot be fully represented. In those cases where the series did decline to zero the average decrease for the first half of the trials was 70 %

Another indication of the difference in the rate at which decrease occurs early and late in a series is found in the size of respective mean variations. Whereas the m.v. usually averages 1.5-2.0 early in a series, it hardly ever rises above 0.5 late in a series. We have already pointed out that the m.v. depends upon a constant decrease in the measures averaged and not upon irregularities due to the method of observation.

(d) The rate of decrease is, again, a matter of individual differences. Subject B decreased at the rate of 1.7 sec. per trial, while subject F decreased at the much slower rate of .2 sec. per trial. The same relative values hold also for the number of movements and for the duration of the apparent movement. Here again, the rate of decrease is greater during early trials than later in the series. In the cases just mentioned, the rate of decrease for the first ten series in subject B was 2.5 sec. per trial and in subject F it was .7 sec. per trial. For the last ten series, subject B showed a rate of .5 sec. and subject F but .01 sec. per trial.

Other averages testify to the decrease of all values from day to day. (1) If the first trials of each day are thrown together, it will be found

that the first trial of any single day is not so large as the first trial of the day preceding, although it may be a little larger than the last trial of the preceding day. That is, there seems to be a small tendency to revert to the original values because of the lapse of the 24 hours. This factor will be studied in detail below. The decrease from day to day as shown by all firt and last turns of rotation to the right and the same for rotation to the left is pictured in Figure 2 (Subject E). This again is a typical curve. It exemplifies the various facts and regularities of decrease from day to day.

(2) There is, however, a still more striking statement of the sensitiveness of nystagmus to practice than we have yet given. So far we have been concerned with decreases from day to day. Table VI shows that decrease also takes place within a single day. Furthermore, the decrease is of the

TABLE VI
Subject E

		Right			Left		
		T	No.	A.M.	T	No.	A.M.
1st 5 Days	Av. 1st 2 Trials	16.6	21.6	14.8	13.9	16.3	14.5
	Av. last 2 Trials	13.6	16.5	13.2	10.9	12.8	10.1
2nd 5 Days	Av. 1st 2 Trials	9.8	11.5	8.7	9.5	9.5	10.2
	Av. last 2 Trials	7.9	8.9	7.4	7.2	7.3	7.7
3rd 5 Days	Av. 1st 2 Trials	8.1	7.6	8.7	6.1	5.4	6.8
	Av. last 2 Trials	5.6	4.9	5.7	4.9	3.6	5.0
4th 5 Days	Av. 1st 2 Trials	4.0	4.0	4.7	4.1	3.7	4.7
	Av. last 2 Trials	2.9	2.6	3.4	2.3	2.2	2.9

Table showing the amount of decrease in time of nystagmus within single rotation-periods of ten trials each. Averages of the first two trials to the right and to the left on the first five days are compared with the averages of the last two trials to the right and to the left during the same five days and so on for succeeding five-day periods.

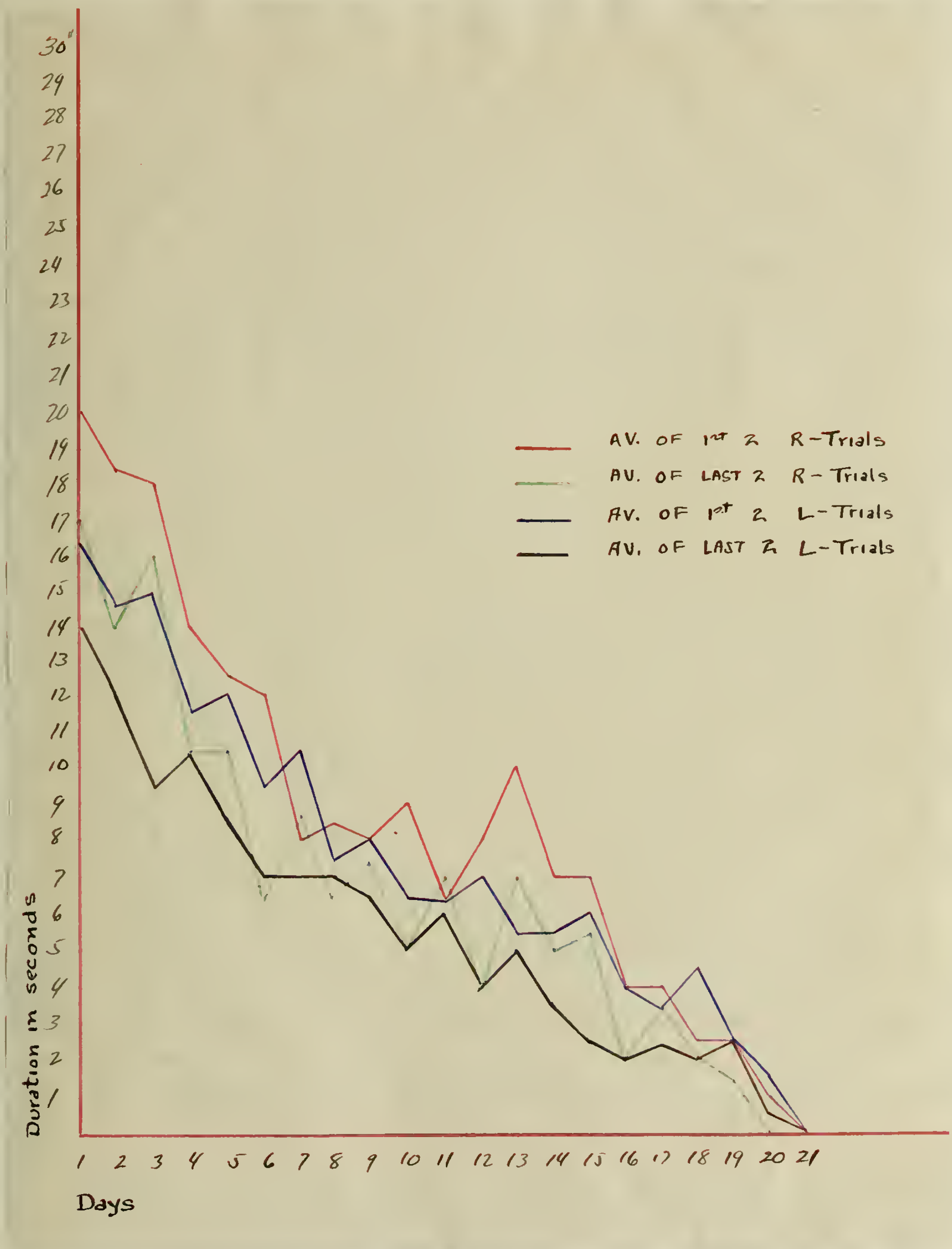

Fig. 2
Subject E

same kind as that already described. It will be noted that the total decrease during the first five days is more than three times as much as that during the last five days. The rate of decrease also is faster.

(3) Again, the decrease of the ocular effects from day to day is demonstrated as follows: the number of movements per second tends, in most subjects, to decrease along with the more apparent decrease of time-values. This fact is a measure of the decrease in the intensity of the ocular effects, while the preceding facts have been concerned only with the duration of the movements and with their total number. For example, subject E decreased from an average of 1.18 movements per second in the first five periods to 0.96 in the last five periods. Subject F decreased from 2.20 to 1.35; subject G from 1.95 to 1.10; subject J from 2.76 to 2.27; subject I from 1.49 to 1.33; subject H from 2.35 to 1.17. Two subject showed a slight apparent increase. It was found, however, that these two subjects, who had very wide initial movements, fell into the habit of gazing fixedly in the field of vision, a procedure which decreases the amplitude of the eye movements but increases the speed and the time of nystagmus.

(4) And finally, we discover that the amplitude of the eye-movements becomes less and less as a series proceeds. Readings of the after-nystagmus taken through a reading microscope show that the eye movements in some subjects decrease from an amplitude of 8 mm. to an amplitude of less than 0.5 mm.[1] For example, in the case of subject O the amplitude of the movements

1. See Bárány, R., Apparat zur Messung der Rollbewegungen des Auges, Zsch. f. Sinnesphysiol., 1911, 45, 59-62, for a description of an apparatus made and used by him for measuring ocular movements. The psychological laboratory has been quite fruitful in describing and measuring different types of eye movement.

took the following course:

TABLE VII

Days	Ampl.	Days	Ampl.
1.	6 mm.	6.	1.6 mm.
2.	4 "	7.	1.2 "
3.	3.5 "	8.	0.8 "
4.	2.4 "	9.	0.5 "
5.	1.9 "	10.	0.0 "

So far we have been concerned wholly with the ocular effects of rotation. It has been pointed out, however, that these effects are but a portion of the whole organic group. Now all of the other effects follow the same course as the ocular resultants. Most of the subjects were more or less nauseated during the first trials. Nevertheless, within a day or two, all nausea disappeared for most of the subjects and within three or four days no trace of it was left. The same is true of the tendency to excessive perspiration and of the tendency to hold the breath during rotation. Again, the head soon ceases to move in the direction opposite to rotation.

We have already observed that one of the principal tests for vestibular 'normality' given by the otologists is the test called "past-pointing." It was found in the case of naive observers that they tended after rotation to point past,-either to the right or to the left of,-any object which had been previously designated. We have found, however, that, after practice, subjects no longer tend to 'past-point' in this way. That is to say, it is possible, by measuring the amount of past-pointing, to demonstrate that, as practice continued, the angle of deflection of the hand and arm became constantly lessened; so that, finally, there was no deviation at all. A quantitative experiment was performed in the following manner. The subject was instructed to hold his arm loosely in front, a pencil held lightly in his fingers, resting upon a large sheet of paper. He was further instructed to let the arm move as

it would and if it should at any time move off the paper, to return as nearly as possible to the starting place and to let the arm again move involuntarily. Under these conditions, it was found that, during early rotational periods, either arm tended to move out and away from the body, no matter what the direction of rotation. During the stopping period, the arm moved in and toward the body for a moment and then resumed its original direction with rapidly decreasing deflection. Finally, it was found that these movements tended to drop out. Figure 3 made up from the actual records will schematize the facts concerning these movements.

Figure 3

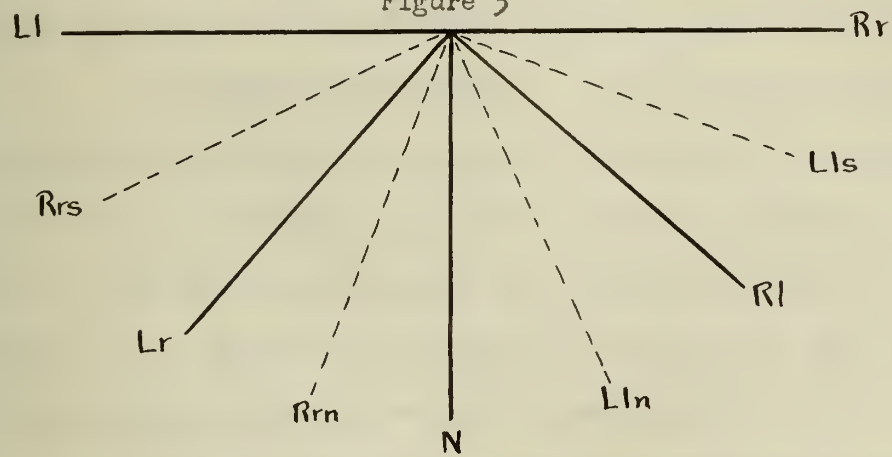

Figure 3. N, the direction of movements made with either hand while the body is at rest. Rr, direction of movements made by the right hand during rotation to the right. Ll, direction of movements made by the left hand during rotation to the left. Rl, direction of movements made by the right hand during rotation to the left. Lr, direction of movements made by the left hand during rotation to the right. Lls, direction of movements made by the left hand just as rotation to the left is ceasing. The direction then changes to Lln and finally to N. Rrs, the direction of movements made by the right hand just as rotation to the right is ceasing. The movements then take the direction of Rrn and finally of N. As practice continues Ll and Rr drop down to Lr and Rl, then to Rrn and Lln and finally take the direction of N as repetitions increase.

It will be seen from Figure 3 that the movement of the right arm to the right during rotation to the right must be caused by a definite innervation of the muscles of that arm. On the other hand, the movement of the

right arm to the right during rotation to the left suggests that the inertia of the arm is the principal factor. The same is true of the left arm. The movement of the left arm to the left during rotation to the left seems to be the result of definite innervation, whereas the movement of the left arm to the left during rotation to the right suggests mere inertia. Introspective reports of the difference in the clearness and intensity of the muscular sensations set up during this time bears out the fact that the one is the result of definite innervation while the other may be only the result of inertia. The lower limbs tend to behave in this same general manner, _i.e._ the right leg during rotation in either direction tends to swing to the right while the left leg during rotation in either direction tends to swing to the left.

B. PHYSICAL CONDITIONS. So far we have found the appearance of nystagmus to be inversely proportional to the number of turnings. That is to say, the time of nystagmus, the time of apparent movement of objects, and the number of eye movements decrease very materially from day to day as rotation is continued. So sensitive is nystagmus to practice of this kind that an appreciable decrease in the above values occurs within a single period of ten trials. We have also pointed out certain peculiarities of this decrease. Furthermore, we have shown that the ocular movements decrease in number and in amplitude, a fact which is paralleled by the decrease and final disappearance of the other organic effects, such as past-pointing. In other words, nystagmus is not a fixed response to rotation; it is clearly affected by repetition. We now proceed to still further evidences of the modifiability of the ocular responses.

1. _Speed of turning_. It has already been suggested that the time of nystagmus is directly proportional to the number and to the speed of turnings. We have found that a single rotation will rarely, if ever, result in any observable effects. After two revolutions, there is usually a flicker

of the eyes. From this number up to the full number ten, the effects increase rapidly in duration and in intensity. Even after much practice any change in the rate of rotation or in the number of revolutions will change the appearance of the nystagmus. For example, near the end of their respective series, subjects E. and H were rotated twice as fast as in the regular series, *i.e.*, ten times in ten seconds. The values from the regular series at this time for subject E were 3.4 3.1 4.4 and for subject H 4.2 5.3 4.4. After the trials at increased speed, the corresponding values for E were 14.5 17.5 14.0 and for H 17.5 35.0 15.5. The very large increase under the new conditions is evidence enough that the speed of rotation seriously affects the appearance of the nystagmus even though much practice has already taken place. It is significant, however, that the larger values are but a fraction of the values obtained at a similar speed before any practice.

2. The mode of stopping. Subject C was stopped slowly and abruptly on alternate turnings, care being taken that no advantage fell in either direction. The average nystagmus for all slow stoppings was 16.9 and the number of movements was 30.9. For abrupt stoppings the averages were 21.7 and 40.6. That is to say, nystagmus is increased both in duration and in intensity when a subject is abruptly stopped.

3. The effect of a brief reversal of the direction of rotation. Returned aviators reported that frequently during the official tests given by the otologists, the rotating chair had been allowed to swing past the correct stopping place and had then been brought back to position before readings were taken. Table VIII shows the results obtained from subject N by allowing him in alternate trials to move one quarter turn too far in the direction of rotation and then to bring him back to the usual stopping place. The additional time required was one second. It is clear that such a brief return move-

ment serves considerably to decrease the time of nystagmus and the number of eye-movements.

TABLE VIII

Trials	Normal stop T	Normal stop No.	Normal stop A.M.	Excess and return T	Excess and return No.	Excess and return A.M.
1st 50	17.5	33.5	17.4	15.7	26.8	15.4
2nd 50	14.2	25.7	14.2	10.9	14.4	10.9
3rd 50	10.5	16.7	10.7	7.4	9.5	7.5
4th 50	9.3	14.9	9.2	6.3	8.6	6.2

C. TEMPORAL CONDITIONS. The organic effects of rotation are also modified by temporal conditions. These are of two kind, viz., the time of day at which rotation takes place, and the interval that lapses between successive rotation periods.

1. The time of day. Subject F was rotated regularly every morning at 7:30 and every evening at 6:30. Both periods came just after meals. Efforts were made to keep other factors constant. The averages for the mornings turnings (32 in all) were 10.4 19.6 10.8 and those for the evening turnings (31 in all) were 9.5 16.1 9.9. That is, the values for the evening trials were a little smaller than for the morning trials.[1] That this difference is more significant that at first appears, may be seen by referring to Table IX. The figures in this table represent the amount by which the evening turnings were less than morning turnings in terms of five-day periods. These results are in keeping with other facts to which we shall soon come, viz., that nystagmus seems to be highly dependent upon the general organic conditions of the subject.

1. See Griffith, C.R., The effect upon white rats of continued bodily rotation, The Laryngoscope, 1920,30, 135.

TABLE IX

Five-day Periods	Time	No. of Mvts.	Time of App. Mvt.
1	1.1	2.2	1.1
2	1.3	6.9	1.3
3	0.5	3.5	0.4
Total	2.9	12.6	2.8
4	0.9	3.7	0.9
5	1.7	4.5	1.3
6	1.1	3.0	1.2
Total	3.7	11.2	3.4

2. <u>The effect of intervals</u>. (a) The effect of short rest intervals between trials. Subjects E and H were alternately rotated with no rest between successive turnings and with rest (2min. between R and L and 3 min. before another pair to R and L) between successive turnings. Subject E shows that the decrease is faster (measured here by smaller averages) when no rest is allowed between turnings (Table X). Subject H yields no positive evidence for the effect of intervals between trials. In other words, we have

TABLE X

	Subj. E			Subj. H		
No rest	T	No.	A.M.	T	No.	A.M.
Av. 1st 50 trials	9.8	11.6	9.2	13.8	29.4	11.6
Av. 2nd 5p trials	3.5	3.2	3.8	-4.6	6.2	-4.5
Rest						
Av. 1st 50 trials	11.7	13.1	11.6	13.1	17.7	12.0
Av. 2nd 50 trials	4.9	4.5	5.4	5.6	5.9	4.7

a further suggestion that the reduction in the time of nystagmus is dependent not upon fatigue but upon some factors at present unknown.

(b) The effect of long rest intervals between series. It was impossible to avoid missing a day or two now and then as the various series went on. We have taken advantage of this fact in Table XI by counting the number of decreases and increases in the values after no interval and comparing

TABLE XI

Subj.	No interval: Decreases T	No.	A.M.	No interval: Increases T	No.	A.M.	Interval: Decreases T	No.	A.M.	Interval: Increases T	No.	A.M.
A	9	9	8	1	1	2	3	3	3	1	1	1
B	5	4	4	1	3	3	1	1	0	0	0	1
D	15	13	15	10	11	9	2	2	2	2	2	2
E	10	10	11	4	5	3	4	4	4	1	1	2
F	33	30	28	22	25	27	0	0	0	5	5	5
G	32	32	33	19	18	18	7	8	7	3	3	4
H	13	15	15	3	1	1	5	5	4	0	0	1
N	10	11	10	3	2	3	2	3	3	1	0	0
P	15	17	15	8	5	8	5	4	5	3	3	3
Q	14	12		6	9		3	3		5	5	
R	9	9		9	10		4	1		1	4	
S	11	10		3	4		4	3		1	2	
T	9	9		6	7		1	3		2	0	
Total	185	181	139	95	101	74	41	40	28	25	26	19

Showing the number of decreases and increases in time, number of movements and time of apparent movement immediately after a short rest interval.[1]

1. Note: Subjects Q, R, S and T were rotated while wearing lenses and it was therefore impossible to secure the time of the apparent movement since the visual field is blurred. Subjects C, I, J, K, L and M were rotated every other day or every three da s and are not, therefore, included in this table.

these sums with the decreases and increases falling after a short interval in the series of one or two days. By inspecting the Table (XI) it will be clear that an interval occurring in a series does not greatly alter the course of the nystagmus. Although there are relatively more increases than there are decreases after an interval than is the case where no interval is involved, yet the difference is not significant. All that can possibly be demonstrated is that the slight dirunal loss of improvement mentioned on p.24 is a little more evident. On the other hand, we can legitemately cite these facts as further evidence that fatigue does not play a part in the decrease of nystagmus during practice.

Still more striking is the persistence of the effects of practice over long intervals of time. We have shown elsewhere[1] that after from four to eight weeks, the effects of practice are still in evidence. That is to say, a subject whose nystagmus time has decreased to 5-6 sec. will some weeks later give, at most, only 8-10 sec. of ocular movement. For example, by referring to Tables II and III (p.17) it will be seen that the last values for subject F in the regular series were 4.0 4.0. Two months later the averages were 7.5 9.7 8.2, and within ten trials (5 to the L and 5 to the R) had decreased to 5.5 7.5 5.5. In a similar way, subject P, who had lost all ocular movement with practice, gave after five months but three seconds of after-nystagmus. Further evidence was gained from five men of long experience in the aviation service. It was found in such cases that, although the first turnings might yield high numbers,[2] but a little practice

1. Paper read before the Illinois State Academy of Sciences, Feb., 1920. To be published in the Proceedings of the Academy.
2. The high initial values of men coming from long practice in flying is not contradictory to our results. They, in common with whirling dancers, show a smaller nystagmus time only when turned under the conditions that have obtained during practice. That is to say, the effect of repetition is immediately apparent under one set of conditions only. Nevertheless, as we shall presently see, there is a rapid "transfer effect."

was required to reduce all the values. For example, subject AA, who had been flying for eighteen months, was tested seven months after his discharge. Table XII shows the results.

TABLE XII

Series	Right Time	Right No.	Right App. Mvt.	Left Time	Left No.	Left App. Mvt.
1	21.0	40.0	21.0	17.0	25.0	17.0
2	18.0	29.0	18.0	15.0	22.0	15.0
3	14.0	18.0	14.0	11.0	12.0	11.0
4	11.0	12.0	11.0	8.0	10.0	8.0

It is clear, therefore, that although the initial nystagmus times and other temporal values may approximate results obtained before practice in flying, the influence of practice is rapidly re-established. Furthermore, none of these subjects past-pointed or gave other report of organic disturbance.

D. THE EFFECT OF THE GENERAL ORGANIC STATE. Some twenty times during the series of investigations subjects came to the laboratory suffering from organic disturbances in no way connected with the experiments themselves. Occasionally a subject came in from violent exercise or from exertion on excessively warm days. In all these cases, the time of nystagmus, the number of eye-movements, and the time of the apparent movement of the visual field were appreciably increased. For example, the averages of all the trials for these subjects just the day before the organic disturbances were 17.4 28.7 16.6. The averages of the trials taken while the subjects were thus organically disturned were 20.1 30.5 19.1. The average of the first trials after recovery (recovery being assumed from the subject's own report) were 16.4 27.2 15.7. From these figures, the effect of the organic disturbance is apparent. Furthermore, the figures show that the effect is only temporary and that, in fact, it conceals a real decrease. In almost every case the results obtained after recovery were found to be about the same as the temporal

course of the nystagmus at that time would indicate should have been the case. In addition to these facts, certain individuals reported on coming into the laboratory that they were feeling unusually fit. In these cases, the average of the trials on the preceding day were 18.7 42.0 18.5, while the averages on the day in question were 12.8 28.4 11.6, and the averages on the following day were 15.4 31.3 15.1.

For example, on July 7, 1919, subject M arose very early, worked hard all morning and was rotated just after returning from a rapid walk on a hot day. The preceding day his average values were 14.3 23.7 12.5. On July 7, the values rose to 18.1 28.2 18.2 while on July 8, the values dropped to 12.3 17.3 and 12.3. This typical case shows that the increase was not a permanent matter, but that it merely covered a real decrease. On Aug. 1 the average values for this subject (M) were 6.8 5.3 and 6.7. On Aug. 2 and 3 when M was suffering from a digestive disturbance the average values rose to 9.8 11.1 and 10.0. But on the next period, the numbers declined again to 6.1 6.9 and 6.5. We have already pointed out, that, in the case of white rats, organic disturbances may have a pronounced effect upon the time of the nystagmus and upon the rate at which decrease takes place.[1] The diurnal differences noted just above may rest upon conditions of the same order. All of these facts suggest the wide organic implications of nystagmus and of the conditions of its decrease. These implications must be considered in any explanation of nystagmus and of its susceptibility to practice. More evidence as to the precise relation obtaining between the organic state and the appearance of nystagmus is sorely needed.

E. MODIFICATION BY 'TRANSFER'. We saw above (p.34) that aviators of long flying experience may have large initial values but that the

1. Griffith, C.R. The effect upon white rats of continued bodily rotation, The Laryngoscope, 1920, 30, 127ff.

[illegible]

effects of practice are rapidly restored. We then suggested that the high initial values were due to a change in the conditions of arousal. By inspecting Table XIII it becomes clear that is sample trials making use of one set of conditions, e.g., rotation without the use of lenses before the eyes, are taken during a series making use of another set, e.g., rotation with lenses before the eyes, there actually is a 'transfer effect' from the one set of conditions to the other. That is to say, the decrease in the time of nystagmus without the use of lenses is paralleled by a decrease in the time if lenses are used at any part of the series. It has been contended by the otologists, for example, that any 'apparent' decrease in the duration of nystagmus may be offset by the use of lenses. Our results show that this cannot be the case inasmuch as a corresponding decrease has occurred when lenses are used temporarily, a modification which is equivalent to the decrease that would have occurred during a constant use of lenses. This modification by 'transfer' may be seen to advantage in the following facts. Subject P, whose initial values were 25.5 47.5 and 26.5 gave, during rotation with the head inclined forward through 160 degrees, a circular nystagmus with the following values: 24.7 35.6 25.0. When the head was placed sidewise the results were 26.9 51.7 28.1. At the end of the practice series under 'normal' conditions, trials were again taken with the head bent forward and to the side with the following results:

TABLE XIV

	Head forward				Head to right side		
	T	No.	A.M.		T	No.	A.M.
Aug. 8	12.2	14.4	14.0	Aug. 12	11.5	27.7	13.2
Aug. 9	12.2	12.5	14.0	Aug. 13	11.2	23.5	12.5
Aug. 10	8.1	10.7	9.7	Aug. 14	9.2	18.0	9.7
Aug. 11	7.4	11.2	8.2				

At the time of the initial trials, the nausea and dizziness were

Table XIII

Subj.	Date	Lenses T	Lenses No.	No lenses T	No lenses No.
	May 14	45.9	53.6	29.0	57.0
Q	July 1	32.6	35.9	14.5	18.5
	" 8	19.9	24.7	9.5	13.0
	" 15	21.3	27.3	7.0	6.5
	" 16	20.8	26.4	7.5	8.0
	" 31	16.1	22.5	5.5	5.0
	May 14	35.9	38.6	25.5	25.0
	" 27	26.6	17.1	18.0	12.5
R	June 2	25.5	25.5	14.0	13.0
	" 5	16.2	10.7	7.5	7.0
	" 10	20.2	16.8	8.0	5.5
	" 14	12.0	7.2	6.0	4.5
	May 13	33.0	53.7	25.0	40.0
	" 27	26.2	43.8	18.0	33.5
S	June 3	20.7	32.9	13.0	22.5
	" 11	17.4	27.8	10.0	17.0
	" 13	15.3	22.7	7.0	13.0
	May 14	50.0	88.5	22.5	63.5
	" 16	39.1	73.7	20.5	52.5
T	" 21	30.1	60.9	15.0	34.0
	" 24	25.5	52.0	12.5	24.5
	" 26	18.7	38.1	9.5	20.0

Subj.	Date	No Lenses T	No Lenses No.	Lenses T	Lenses No.
	May 12	25.5	47.5	44.5	29.5
W	July 10	11.8	15.5	16.0	6.0
	" 14	7.3	5.5	11.0	20.5
	" 30	4.7	4.0	15.2	9.0
	Aug. 1	4.2	3.2	11.0	10.0
	July 12	15.9	10.8	37.0	29.0
O	" 19	1.9	2.0	15.0	9.5
	" 28	0.1	0.1	9.0	5.0
	June 30	18.7	35.0	32.0	49.0
	July 10	10.3	22.8	27.5	39.5
N	" 17	7.8	11.4	15.5	27.5
	" 19	6.9	9.9	13.5	24.0
	May 16	24.5	56.1	31.5	67.5
	" 30	7.1	12.0	21.0	44.0
H	June 12	1.3	1.5	11.0	5.5
	14	0.0	0.0	8.5	5.0

Showing that decreases while wearing lenses are paralleled by decreases without senses. Also that decreases without lenses are paralleled by decreases with lenses.

severe, but at the end of the 'normal' series, the subject experienced no uncomfortable effects of the unusual position, showing that the effect of practice was more deep-seated than the ocular effects alone. Moreover, this subject, and also other subjects have enjoyed an increasing ability to change the position of the head both during and after rotation without experiencing the tremendous increase in the intensity of the organic effects which usually accompany such a change in position.

CHAPTER V

CONCLUSIONS

We have discovered, then, the following facts about the organic effects of rotation, especially about the local effects called nystagmus. We have found that, as turning is repeated from day to day, the duration of the after-nystagmus, the number of ocular movements made, and the duration of the apparent movement rapidly decrease. The major part of this decrease occurs within the first few days. The decrease takes place not only from day to day but also within a period of ten trials on any single day. The amplitude of the ocular movements and the number of movements made per second also decrease as repetitions increase. Furthermore, certain other organic effects, especially those known as past-pointing, decrease in the same manner. We have also found that the time of nystagmus changes with the speed of rotation and with the number of revolutions and that it is increased when the chair is abruptly halted. As to other conditions under which nystagmus varies in degree and amount, we have found that we must consider: (a) the time of day during which rotation is carried on; (b) the amount and number of rest intervals between turnings and between series; and (c) the general organic state of the subject. Finally, nystagmus may be modified indirectly by 'transfer.' In general, we have found the organic effects of rotation to be highly variable in their appearance and, moreover, so amenable to practice that they may entirely disappear within a relatively short time, provided rotation is repeated from day to day.

PART TWO

THE MENTAL EFFECTS

CHAPTER I

INTRODUCTION

A. HISTORICAL SETTING. Scientific interest in dizziness and vertigo began as long ago as 1795, when Erasmus Darwin[1] first summarized the facts as then known. Purkinje, however, seems to have been the first writer to put the matter to a test in the laboratory.[2] His experiments, which have since become popularized in the parlor game of whirling with inclined head about a stick, led to a remarkably complete account of the apparent movement of objects in the visual field after rotation. He noted, for example, that the curious movement of such objects always took place in a plane perpendicular to the axis of rotation, no matter how the head was subsequently moved. By way of explanation, Purkinje related all of his observed facts to inertia of the soft parts of the body, particularly the brain. So impressive, it seems, was his demonstration that, for a number of years, no further descriptions were given.

In fact, it was not until 1875 that anything further was added to the psychological description of dizziness. In that year, however, Crum Brown[3]

1. Darwin, E., Zöonomia, the laws of organic life, 1795 (3rd ed., 1801), pp. 327-356.
2. Purkinje, J. Beiträge zur näheren Kenntnis des Schwindels nach autognostischen Daten, Med. Jahrb. d. Osterr. Staates, 1820, 6, 79-125.
3. Crum Brown, A., A preliminary note on the sense of rotation and the functions of the semicircular canals of the internal ear, Proc. Roy. Soc. Edin., 1874, 8, 255-257; 370-371. See also J. of Anat. & Physiol., 1874, 8, 322-331.

and Mach[1] independently attacked the problem in such a way as to show just where the future task was to lie. Crum Brown was the first to use the phrase "the sensation of rotation", and since his time frequent references have been made to an 'equilibratory sensation,' to a 'sensation of motion', and to 'static sensations.' The tendency towards this use was undoubtedly strengthened by an accumulating body of evidence that a new end-organ discovered, in the years just preceding, in the semicircular canals, was closely related to bodily movement and to the maintenance of equilibrium. Crum Brown concluded his investigations in the following manner: "As far as I am aware, the sense of rotation has not hitherto been recognized either by physiologists or by psychologists as a distinct sense; but a little consideration and a few experiments seem to me to be enough to show that it really is so. By means of this sense we are able to determine,--a, the axis about which rotation takes place; b, the direction of the rotation; and c, its rate..... In ordinary circumstances we do not wholly depend upon this sense for such information. Sight, hearing, touch, and the muscular sense assist us in determining the direction and amount of our motions of rotation, as well as of those of translation; but if we purposely deprive ourselves of such aids we find that we can still determine with considerable accuracy, the axis, the direction, and the rate of rotation."[2]

Crum Brown's reference to the part played by other sense-departments applies also to another mode of attacking the question, <u>viz</u>., that adopted by Mach. We have already seen that Purkinje sought to explain the facts of rotation by appealing to the inertia of the soft parts of the body and to the

1. Mach, E., Physikalische Versuche über den Gleichgewichtssinn des Menschen, Wien. Sitz. d. kais. Ak. d. d. wiss., 1873, 68, 124-140; Grundlinien der Lehre von den Bewegungsempfindung, Leipzig, 1875.
2. Crum Brown, A., Proc. Roy. Soc. Edin., 1874, 8, 255.

sensations resulting therefrom. Early in the history of the semicircular canals the close relationship between the canals and the musculature of the body had been noted. Furthermore, a good deal of attention was given to Sir Charles Bell's alleged 'muscular sense.' It is not strange, therefore, that the perception of position and of movements came to be described in terms of sensations from the skin, the joints, the muscles, and the eyes. In 1875 Mach came to the conclusion that although "die Bewegungsempfindugen lassen sich nicht erklären durch die Wirkung der sensiblen Elemente der Knochen und des Bindegewebes, nicht durch die Wirkung der Haut, der Muskel, des Blutes oder des Hirns", nevertheless "ein Mitwerken dieser Factoren bei Erkenntniss der Locomotion nicht vollständig ausgeschlossen werden kann."[1] Later he concluded that of the mental processes involved in the perception the most important is that of vision which, combined with 'skin-sensations' and 'with changing innervations' yields 'a conception of our body as in motion.' Mach doubted that 'special motor sensations exist which proceed from this apparatus (_i.e._, the canals) as from a sense-organ', but he thought that the apparatus simply 'disengages innervations after the manner of reflexes.' He regarded as untenable, then, the view that knowledge of equilibrium and of movement is directly mediated by means of the semicircular canals.[2] In a similar way, Wundt has questioned the existence of special sensory qualities from the canals, since the deaf and dumb acquire "mit Hilfe anderer Sinne, namentlich des Tast- und Gesichtssinnes, eine so vollständige Orientierungsfähigkeit im Raume, dass er, so schwer er den Mangel des Gehörsempfinden mag, den dieses Orientierungsorgans kaum zu bemerken scheint.".... Eine Organ, das in solcher Weise durch anderer vertreten wird, kann aber keine spezifische, nur ihm eigentümliche

1. Mach, E., Grundlinien der Lehre von den Bewegungsempfindungen, Leipzig, 1875, p. 125.
2. Mach, E., Analysis of the sensations (tr. Williams), 1897, pp. 65-66; 73-77.

Funktion haben."[1] Wundt finds, however, that the "tonische Organ" is functionally related to the other senses. These facts led him to conclude that "der tonische Sinn kein für sich isolierbares Vorstellungsgebiet imfasst, da er niemals für sich allein Wahrnehmungen des Gleichgewichts und der Bewegungen des Körpers oder gar des Raumes im allgemeinen vollziehen kann, ähnlich wie ja selbst der Sehende niemals durch den blossen Tastsinn Wahrnehmungen äusserer bestateter Objekte gewinnt, bei denen nicht, auch ohne dass er es will, Assoziationen mit den Vorstellungen des Gesichtssinnes mitwirken." The semicircular canals are for him "a kind of inner organ of touch."[2]

Holt has made the first really serious attempt to analyze the experience of rotation. He has found, for example, that rotation yields three groups of processes. The first group is made up of "sensations which proceed from extra-peripheral stimuli," such as currents of air, light, and sound. The second group "are the sensations from proprio-ceptive organs in joints, limbs, internal organs, and even perhaps of the blood, and by their centrifugal moment." Finally, in the third group are "the true sensations of motion;" and of the three groups these "true sensations of motion" are the only ones essential. On examination, however, these sensations prove to be merely the feeling that either the body or objects about the body are in rotation or else they are more or less parallel to "innervations of one kind and another."[3]

Recent writers of text-books have met the problem in the traditional way. The usual descriptions of the ear and of the flow of the liquid and of the reflex nature of the responses, together with a description of the field of vision during dizziness, make up the chapters on this "sense-de-

1. Wundt, W., Grundzüge der physiologische Psychologie, (6th ed.), 1910,2, 507.
2. Wundt, W., op. cit., p. 508.
3. Holt, E.B., On ocular nystagmus and the localization of sensory data during dizziness, Psychol. Rev., 1909, 16, 377-397.

partment." In its simplest form the psychological problem has been stated thus: Does the excitation of the canals result in a new sensory quality or does the experience gain its character because of the kind and number of other sensory components? Pillsbury states the question in this form and answers it provisionally only. He "speaks for the view that the sensation of giddiness is not a true sensation of the vestibular nerve, but rather a sensation of the alimentary canal, due to reflexes excited by the organs of equilibration" and that "visual sensations, kinaesthetic sensations, and sensations due to displacement of the large visceral organs also aid in keeping the balance and in appreciating the movements of the body."[1] Titchener is persuaded that the canals act "reflexly, without furnishing sensations, or at any rate furnish sensations of little strength, and of a pressure-like quality that blends indistinguishably with the kinaesthetic sensations from tissues beneath the skin."[2] But he also finds, under other conditions, sensations appearing as a compression or lightness in the head, and a distinct feeling of squeeze in the region of the ears.[3] Warren is still more positive of vestibular sensations of a "particular quality". The "sensations of position and sensations of motion" are not only different in quality from one another but "the sensations from the three semicircular canals may also differ in quality" just as local signs are found in the sense of touch.[4] Külpe[5] is quite doubtful of a new sensory quality, although he does admit that "giddiness" may be taken as representing the activity of the canals in consciousness; but "it is difficult to

1. Pillsbury, W.B., Fundamentals of psychology, 1916, p. 203.
2. Titchener, E.B., Text-book of psychology, 1910, 173-182.
3. Titchener, E.B., op. cit., pp. 179-180.
4. Warren, H.C., Human psychology, 1919, p. 213.
5. Külpe, O., Outlines of psychology, (tr. Titchener), pp. 150ff; p. 378. In Titchener's more recent book (A beginner's psychology, 1915, p. 56) he speaks more positively of the"sensation of 'swimming' when the head is sharply jerked, and the sensation of dizziness when we twirl on our heels."

[illegible]

say what the common element in sensations of giddiness is when we have abstracted from the objective disturbance of the co-ordination of movements and its various concomitant phenomena."

B. THE PROBLEM. It is clear, therefore, that no common opinion is to be found among the writers we have mentioned in this brief historical survey. In fact, we can point out at once two phases of a problem upon which further evidence is needed. In the first place, there is an urgent demand for a more detailed and adequate description of all the processes that arise when a subject is rotated. Furthermore, it will be necessary to classify these processes as regards their importance in the experience of dizziness. That is to say, there are undoubtedly some processes more or less essential to the appreciation of rotation and the selection of these processes must be based upon experimental evidence. This task leads directly to the second phase of the problem. Is there a process or group of processes which stand related to the end-organs in the semicircular canals as the visual processes stand related to the rods and cones in the retina?

Another problem concerns us in this investigation. It springs from a recent clinical use of the term 'vertigo'. We refer to a current distinction drawn by the otologists between vertigo and an ocular effect of rotation commonly known as "nystagmus".[1] Now nystagmus is,-as they maintain,-a simple reflex, and it is not, therefore, subject to change under practice. In the previous section we have shown that this contention is without foundation. We have there shown, on the contrary, that the ocular effects, as well as all the other organic effects of rotation, tend to decrease and finally to disappear under repetition. Our parallel problem here, then, will be to determine the probable modification of the mental results of rotation. In brief, this is our

1. See, for example, Jones, I.H., Equilibrium and Vertigo, 1918, p. 5.

present problem. (a) What are the mental processes aroused during stimulation of the end-organs of the semicircular canals and what is their relative significance to the experience of rotation as a whole? And (b) what effect will continued repetition and other factors have upon these mental processes?

CHAPTER II

THE MENTAL EFFECTS OF ROTATION

Our method of experimentation has already been described in the foregoing section, which was devoted to the bodily consequences of rotation. The method was the method of periodic repetition. In each trial our subjects were revolved ten times.[1] There were ten successive trials taken each day for a considerable number of days. Introspective reports were called for after each trial. The instructions were varied from time to time, as we shall presently designate. We varied our conditions one after another, and we submitted the whole experience to an elaborate fractionation in time. In congruence with previous investigators, we have found that continued rotation results in an experience which is highly complex. We now proceed to an analytic description of the experience on its mental side, first by way of gross description and afterward with detailed analysis.

A. PRINCIPAL AND ACCESSORY PROCESSES. Of the principal processes that are aroused by rotation we may mention clear kinaesthesis from the eyes, from the head and neck, and from the limbs. Also, there are visceral

1. The writer wishes to express his appreciation of the services of the subjects in this part of the investigation. They were V.B. Adams, M.A. Beard, A.R. D'Angelo, W.A. Diesel, M. E. Broom, L.K.Cecil, A.R. Elliott, L.R. Raines, R.W. Wuestermann. H.C. Burleson noted the results from the writer.

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pressures, coolnesses, and surging or 'welling' qualities. Pressure and even pain may be localized deep within the head and high upon in the nasal passages, while all kinds of pulling strains are reported from the region of the diaphragm. Occasionally some of these processes become clear and reach a climax in the experience of nausea. The processes of this group appear to be aroused by some other cause than the inertia of the body or the fact that the body is rotated in a resistant medium. On the other hand, and in accord with Holt, we have put into the group of accessory processes such events as are obviously aroused by the inertia of the body, *e.g.*, changing pressure on the buttocks and at the back of the head. In addition, a slightly cool pressure can be localized on the side of the face toward rotation and there is a continuous displacement of the direction of sounds and of lights and shadows.

CHAPTER III

THE FACTORS WHICH MODIFY THE MENTAL RESULTS OF ROTATION

All that we have said elsewhere of the organic conditions and results of rotation holds true,as well, for the mental concomitants and effects. Not only is the complexity of mental processes markedly reduced under periodic repetition, but the numerous effects of rotation are just as sensitive to variations in their ~~and~~ mental setting as we have found the organic effects to be to variations in the physical and organic conditions.

A. PHYSICAL AND PHYSIOLOGICAL FACTORS. We are here obliged to insist again that the organic and mental results of rotation are not two different groups but that they constitute a single experience. The organic group provides the conditions for the modifications of mind. We may expect, therefore, that any change in their appearance, as a result of changes in the physical conditions of arousal, will be paralleled by corresponding mental changes. We have found, for example that variations in the rate and number of turnings, the mode of stopping, the time of day, the length of an interval between turnings, and the general organic set are conditions under which the organic results are modified. The mental effects are likewise modified under the same conditions. For example, the intensity of apparent movement in the visual field and the feeling of 'dizziness' are greatly increased by a sudden stop or by a reversal in the direction of actual bodily movement. These effects are likewise of greater intensity when the organic state is abnormal, or when no rest intervals are given, or when the rate of rotation is increased, and so on.

B. PERIODIC REPETITION. A refined analysis of the mental effects of rotation is made possible only by the proper fractionation of the whole course of events. As we have seem, under rotation mind is exceedingly complex. The mere fact that such gross designations as "vertigo" and "dizziness" have delayed further analysis for decades bears testimony to the unusual character of the mental effects produced. We have already pointed out that most of the complexes involved are kinaesthetic and organic, and every introspective psychologist knows how tenaciously such complexes resist analysis. The very discovery, however, that this complexity does decrease under repetition is an advantage; for the gradual disappearance of one process after another makes possible a fuller description of those that remain. Again, the very disappearance of certain processes betrays their presence in a preceding stage. The period of rotation has, for our purposes, been fractionated as follows: (a) The period preliminary to any given day's rotation; (b) the period beginning with the 'ready' signal and ending with the perception of the first impulse of rotation; (c) the period during which the speed of rotation is constant; (e) the period from the application of the brake to the inception of the after-nystagmus; (f) the period from the appearance to the disappearance of the after-nystagmus; (g) the period from the end of the after-nystagmus to the next turn; (h) the period following the completion of the day's series. We shall now proceed to discuss each of these periods.

(a) <u>The period preliminary to the day's rotational series</u>. The description of this period is, of course, quite incidental. There are aroused, however, certain processes which supply a constant factor throughout the experiment and w ich have, on that account, to be substracted each time from the whole group of processes which appear under rotation. Among them are the tactual processes from contact with the chair and various cutaneous and subcutaneous pressures indicative of the maintenance of posture. The subject

is not in the most comfortable position, for the head is bent forward, and, in some cases, the knees are slightly cramped. This position gives rise to achy pulls in the back of the neck and the characteristic fatigue-like pressure about the knees from holding one position for any length of time. It has been found, however, that these processes which arise from the sitting position can be readily detected and left out of account when describing the distinctive mental effects of rotation. The five subjects from whom introspective reports were obtained were instructed to take account of these processes before each day's series and to discriminate them as carefully as possible from the processes set up by rotation.

(b). The period beginning with the 'ready' signal and ending with the perception of the first impulse of rotation. The second period corresponds to the preparatory period (Vorperiode) of the reaction experiment. Before rotation begins there is a flood of visual imagery and of kinaesthetic processes. This is the only time at which these processes are at all numerous, for the rotation period itself is peculiarly devoid of imagery so far as our subjects reported. The Kinaesthetic processes come as characteristic pervasive thrills, tension about the abdomen and about the chest as in holding the breath.

"I felt this time just as if I had plunged into a tank of cold water. There is a peculiar gripping about the chest and a thrilly feeling deep inside." (P)

For some subjects these processes mean a fairly complete reinstatement of past experiences in swings, on merry-go-rounds, and especially in high places. All of these processes form a background to the 'feel' of expectation which is carried in part by the verbal kinaesthesis meaning "what is it going to be like?", and in part by a pressure quality from the throat, diffuse kinaesthetic pressures and pulls from the whole body, meaning a kind of setting or preparation against something about to happen, and a very clear

thrilly tingling about the 'pit of the stomach' which radiates in all directions and which is more or less pleasantly toned. The kinaesthetic processes are localized in the lower limbs, the arms and the buttocks and in the facial muscles, especially about the mouth. After several turnings, the visual and other extraneous imagery almost completely drops out. But the processes constituting 'expectancy' are fairly constant and may reappear at any time. They may even become quite definite in their anticipatory reference.

"Had a very peculiar experience this time. The processes meaning expectation all suggested rotation to the left. Instead I was rotated to the right and there was instituted the same kind of reorganization as is usually experienced only when stopping." (P)

Toward the end of the series, however, they become fleeting, more like a suggestion of expectancy, just as the experimenter puts his hand to the chair to begin rotation. As would be expected, all of the processes of 'expectancy' blend into the groups of similar processes aroused just after rotation begins. In case any subject has been previously nauseated, this second period is characterized also by clear olfactory imagery. The writer has been surprised at the readiness with which this imagery is aroused as a part of the 'feel' of expectancy. They carry the meaning of disgust and repugnance and are, in some cases, the signal for the arousal of a kind of psychophysical attitude expressed in the exclamation: "I am sure to be nauseated." In case a subject has become nauseated by the turning, (care was taken continually to prevent it when possible) the olfactory processes form a fairly constant part of the preliminary period through a large part of the series, even though all hint of nausea has long since dropped out. In such cases, it augments the intensity of the 'feeling of expectation', especially the organic components and leads to a kind of permanent psychophysical disposition just the opposite to that induced in one of the later periods (see below).

(c) The period during which rotation is attaining maximal speed. Extraneous processes which are similar to Holt's first group can be briefly described. It is difficult to estimate just what part they play in producing the apprehension of rotation during the first turns of a series. That it may be a large part is suggested by the fact that, as the series proceeds, and other processes drop out, they come to carry almost the whole meaning of rotation. Among the processes found in our experiment are (1) a changed distribution and intensity of pressure from the occiput (head-rest), (2) kinaesthetic sensations in the arms and in the lower limbs aroused by resisting the inertia of the body and (3) most prominent of all, a rather clear and intense change in the pressure about the buttocks, probably due to a slight shift in the centre of gravity of the body. There is also a light cool pressure on the side of the face in the direction of rotation, lights and shadows begin to move across the field of vision, and there is an apparent change in the direction of extraneous sounds.

Other processes are, however, of more immediate interest. The clearest of these is (4) an intense kinaesthetic play about the eyes. Distinct changes in the quality of these processes can be detected. There is a kind of pressure about the eyeballs which increases in intensity and in distribution and then suddenly gives way, only to return again, and so on in rhythmic fashion. Our observers found it impossible to localize this kinaesthesis on one side of the eyeball rather than on the other. The whole eyeball seemed affected. As the series proceeds, the intensity of this first kinaesthetic flutter about the eyes seems to decrease until, at the end, it has almost, if not quite, disappeared.

"Just as rotation begins there is a decided play of tension or pulling about the eyes." (P)

"As rotation starts there is a kind of kinaesthetic setting about the eyes." (K)

"Just as rotation started I felt the usual kinaesthetic flutter about the eyes." (L)

"The usual rhythmic processes about the eyes hardly ever occur any more. The rotation starts with no more concern than as if I shook my head." (P)

Just before the speed of rotation reaches its maximum, there is aroused in unpractised subjects, a tremendously complex mass of kinaesthetic and organic processes from almost the entire body. Constituents can be localized more clearly in the lower limbs, the side of the body toward the direction of rotation, in the arms and the shoulders, all about the chest, in the back and, most clearly of all, in the neck and about the face. During the first periods of rotation these processes arise immediately after rotation begins and reach a high degree of complexity by the time the rotation has come to its maximal speed. The organic or visceral processes then continue in an intensified form from the processes making up the 'feel' of expectancy. This is particularly true where those processes have carried an incipient nauseation. After rotation has been continued for some time these processes do not arise until the end of the second or third turn. All that is left in this period after long practice is the fleeting kinaesthetic flutter about the eyes just before rotation comes to full speed. The swimming feeling does not enter into this preliminary period.

"The ocular kinaesthesis at starting has now become but a faint quiver. It disappears during rotation." (K)

(c) <u>The period during which the speed of roation is constant</u>. The complexity of this period of rotation is at first so great as to make an adequate description almost impossible. It is not strange that the whole group of events making up the period have been dismissed with such words as "vertigo" or a "swimming sensation." As before, the extraneous processes may be profitably eliminated. The pressure about the back of the head arising from the head-rest becomes in this period a clue to the proper position

of the head for the head tends to swing in the direction of rotation. The most prominent of the other processes are the succession of lights and shadows and of sounds that flit by. The cool pressure which begins with the rotation, continues throughout this period, but it is of small significance during first turnings. So also with the pressure from the arms and the buttocks. One group of extraneous processes, however, does play a special part in the experience. For one observer, visual and tactual images of a long smooth oily steel rail, like the smoothness of a piston rod in an engine, carry very largely the meaning of rotation.

"There was present this time a kind of tactual imagery of smoothness and oiliness which took up the whole of consciousness. The effects of rotation were not nearly so marked." (P)

Sometimes the kinaesthetic and organic qualities so completely disappear that the subject regards himself as standing still and the visual shadows and the auditory qualities as floating past him. On these occasions, the after-effects are greatly reduced,-especially the organic complexes. On the other hand, there is a type of visual imagery which carries the meaning of a dizzy height around which the subject is being whirled and from which he is looking down into a dismal abyss. Such imagery was usually accompanied by a marked increase in all the muscular and visceral effects of rotation; the after-nystagmus was longer, and the whole experience much troubled. The appearance of these or of any other imaginal materials of a similar kind was, however, rare.

"Frequently today had visual imagery of various moving objects, and some verbal kinaesthesis in counting the number of rotations, but such processes are generally rare." (P)

As the daily sessions continue, all the effects become greatly reduced in clearness, duration, intensity and qualitative characteristics. As this reduction takes place, there is a corresponding increase in the part that the extraneous processes play. Finally, the whole meaning of rotation is

carried by them, although the kinaesthesis about the neck is still clear. This latter gives the meaning of some kind of movement and it might be found that with the other processes eliminated, it is sufficient to carry the meaning of rotation. It still retains its characteristic distribution on the side of the body toward rotation, as do also the vague remnants of the processes that were formally so clearly localized about the arms and legs. It can be safely said, however, that as rotation continues, the perception of it comes to be carried more and more in terms of the extraneous processes rather than in terms of the remnants of kinaesthesis.

The extraneous processes are almost the only ones which maintain their intensity unchanged whatever the amount of practice. As the other processes begin to drop out, these processes come to play a larger and still larger part until at last they give almost the entire perception of the direction of rotation.

"Rotation seems to be carried almost entirely in terms of the extraneous processes today." (K)

"The perception of movement was carried this time very largely in terms of tactual, thermal and auditory processes." (K)

"Was quite sure this time that in addition to the usual kinaesthesis about the neck and face, the only processes which carried the meaning of the direction of rotation were the tactual processes,-coolness of air, and the auditory qualities. (P)

"The perception of rotation carried very largely in terms of coolness, etc.,today. I believe that if they were not present, I would not be able to distinguish between rotation and linear movement. The neck and the face kinaesthesis might carry the meaning; but I doubt it. (M)

All of the organic and kinaesthetic processes which were aroused during the starting period run their course with a good deal of intensity as rotation continues. The rhythmic kinaesthesis about the eyes becomes almost painful. By the time the first turn is completed the whole body is involved. The visceral qualities may become violent. The somewhat diffuse thrilly qualities of 'expectancy' suddenly become localized into a kind of drawing pressure about the 'pit of the stomach' and gradually rise to a point just below

the diaphragm where part of the intensity is lost in favor of a pulling pressure throughout the diaphragm and in the abdominal walls and a part in favor of tension about the colon and the anus. From the diaphragm there ascends into the oesophagus, a heavy pressure which causes a sort of gulping. (P) Just as the pressure in the diaphragm comes to full intensity, a very diffuse warmth spreads over the whole body, perspiration starts, a bad taste appears in the mouth, there is an excessive flow of saliva, an achy spasmodic pressure about the stomach and unless rotation is stopped, a 'nauseated feeling' spreads over the whole body and vomiting may take place. (P, N, L, K). In the meantime, a lumpy pressure or swelling has arisen deep within the chest and has ascended to the head, where it may spread out, as diffuse achy pressure, or it may become localized about the side of the head toward rotation or over the eyes. (P,K) There then appears a kind of swimming within the head and with this feeling the individuality of all the other effects is lost. Even the very clear tensions and pulls in the arms, neck, back, legs, face, and especially the eyes, seem to lose their specific character and become fused into the 'swirling sensation.' To quote from the records:

"There was a kind of stuffy ache in the stomach and in the higher viscera, and a kind of tenderness and pressure at the anus." (P)

"There was an unpleasant kind of pressure low in the trunk and a periodic pressure and pulling about the anus." (N)

"Found this time a kind of tension about the anus, and similar in quality to that about the chest." (P)

"Felt decided tension in the diaphragm, the abdominal wall and up through the chest, becoming less clear about the throat but very clear at the base of the brain and in the head. There was a distinct 'swelling' pressure in the head." (K)

"Felt this time a kind of spasmodic pressure or pulling at the lower end of the oesophagus and in the stomach region. Also distinct pressure about the anus." (P)

"There was a general organic thrill of expectancy just before rotation began. This became definite but of same quality; after rotation started it was high in the viscera. After two or three revolutions it became fused with other processes from the legs, arms, eyes, etc., so that it was hard to isolate them any longer. Just then a swimming quality developed. Later a distinct pressure bobbed up within the lungs near the heart and there was a slight 'choking' complex." (K)

"Vertigo seems to be entirely a matter of a peculiar fullness

in the head and a pressure localized almost painfully about the nose and in the eyes." (P)

"Very peculiar change this time. Previously it has been hard to single out the items because they seemed so confused and the peculiar whirling sensation in the head which seemed to depend upon an odd kind of pressure and lightness confused me. This time, however, the whole experience seemed broken up. There were many specific items to be found but the swimming sensation was no longer present." (M)

"This time the whole experience was again broken up save that just at the last when I seemed to lose control of myself. Confusion set in and there was immediately a fleeting return of that whirling sensation in the head." (P)

"This time, just as the confusion and whirling sensation began, I set myself as definitely as I could against it. The setting was carried mainly in terms of pressure in the feet and buttocks as if I were trying to hold back an automobile. With this setting the confusion disappeared, as did also the swimming, and I was then able to describe clearly the several single items." (N)

"Seems as if there was a large fluid mass in the head which was whirling around very rapidly and which feels very much as a flowing stream of water looks. This became very confusing until I set myself against it. It then seemed to break up into pressure in the head and also a lightness on one side, and also pressures and pulls all about the face and neck and especially in the eyes." (P)

It is clear that the 'swimming sensation' is not a permanent part of the experience of rotation. Within a few turns it has entirely disappeared and does not return again. In fact, as rotation continues from day to day, all of these events decrease in intensity and duration, and in the end almost all of them disappear.

"I found the usual processes present this time but again all of them were barely noticeable. There was slight kinaesthesis about the eyes as rotation started and then in the neck and arms and a little about the chest (slight tendency to hold breath yet). There were only very meager pressure qualities from the viscera." (P)

"No particular processes today. Everything has become but a vague hint of what it used to be." (M,N)

"Tension about the rectum, abdominal wall, some internal pressure and chest kinaesthesis all of low intensity are the items in a kind of setting or attitude of tension which is present during each period of rotation now. This is coupled with the neck-and-arm-and-face tension. Both of these are different from those qualities which seem like an internal rising coolness which becomes pressure in the neck and in the head and nose." (K)

The visceral qualities change a little as practice continues. It is as if they were being exposed to the air and a light cool breeze were blowing upon them giving a very curious but delightfully pleasant thrill.

This thrilly quality lasts but a turn or two and then rises and changes into a weak and diffuse pressure about the diaphragm. Finally even this thrilly quality drops out and all that is left is a dim pressure about the diaphragm.

"A very diffuse head and stomach pressure as from the presence of a lightly distended balloon seems to be about all that is left of the former organic complexity." (P)

"The eye kinaesthesis has become reduced to vague hints." (K)

"Dim organic processes pretty well diffused through the diaphragm and lower oesophagus were about all this time." (K)

"Some kinaesthesis about the chest, as in holding the breath, very slight organic pressures and pullings in the visceral organs, and some pressure which arose and spread out through the diaphragm and about the lungs." (M)

With the disappearance of some of these more prominent items, it is possible to attend to a new group.

"Behind this group of clear and distinct processes which formerly seemed to make up the core of vertigo, is a dim, diffuse, undifferentiated mass of processes no one of which seems to rise above another, but on various occasions, such as stopping, the mass seems to shift in color or size or position, or something of that kind. This shift is very subtle, like the changing curtains of an aurora borealis. When one watches an aurora it seems to change; but what is changed or at which place cannot be described. You know it has changed. So here, these background processes change as rotation starts and then, as full speed is attained, there is a settling back or retreating until the stopping period. Occasionally definite processes shoot out like a streamer from the aurora. These processes are always pulls or tensions or pressures from the trunk near the diaphragm and often there is a feeling of warmth or of coolness from the visceral region. The warmth is localized higher up and more peripheral than the cold. The affective quality is quite variable." (P)

Just what neural conditions are responsible for this background of undifferentiated processes is hard to say although the work of Camis[1] and others suggests that the stimulation of the canals may have a more definite effect upon vascular and motor conditons than has as yet been determined. Historically,of course, the notion that there are movements of the viscera and of other soft parts of the body which account for the perception of movement has

1. Camis, M., Contributions á la physiologie du labyrinthe; Observations ulterieures sur des phenomenes vaso-moteurs, Arch. ital. de biol., 1911, 56, 277-288; La glycosurie consécutive á la destruction des canaux demi-circulaires chez les chien, ibid., 289-300.

been a common one. Four of the subjects reported this organic shift just after the major complexity of vertigo was gone. It seems to have dropped out during the later trials.

A third group of organic processes consists of a very dull kind of pressure or 'swelling' which seems to arise out of the trunk and ascend into the head like the raising of the level of water in a tank. These are the processes which come most directly from the disappearance of vertigo. As rotation continues, this pressure becomes more intense and clear, being localized sometimes about the ears, sometimes over the eyes, but generally deep within the head. Along with this pressure there is also a decided pressure from the upper part of the nose, and the internal part of the nose feels raw,-just as if one were about to suffer a recurrent nose-bleed.

"Found this time that the pressure about the upper part of the nose, as in nose-bleed, was more clear and dinstinct. The nose became tender and raw." (P)

"The pressure rising at the back of the head became heavy and achy this time as rotation continued." (K)

"The headache I had at the beginning of the turning was changed into a distinct pressure quality high up in the nose." (L)

"Pressure in nose this time and also a kind of fresh feeling of tenderness as if one had just douched the nasal passages with salt water." (P)

Here again the effect of practice is to decrease in intensity and duration all of the processes concerned. Other things being equal, the decrease in the intensity of the processes aroused by rotation proceeds without interruption until all that is left during the actual rotation-period is the rather diffuse kinaesthetic quality from the face and neck.

"All qualities are becoming less and less intense and shorter, save those from the neck and about the face." (N)

These processes which were not at all clear, gave promise of disappearing altogether. As practice continued, they arose later and later in the turning period until, at the end of the series, they appeared only when the rotation was half over.

"Neck-kinaesthesis and nose-pressure not apparent this time until the rotation was half over. None of these processes ever appear any more until late in the rotation-period." (P)

"Did not get anything clear until rotation was almost over. Then only the vaguest hints of pressure from the viscera and kinaesthesis from the face." (M)

There was no change in the quality for rotation to the right or to the left save that the kinaesthesis was always clearer on the side toward rotation, the pressure from the head appearing to change location with the direction of rotation, especially late in the series. Just what kind of a change this was could not be determined. Also all processes seemed to be a little clearer during rotation to the right than to the left with two subjects.

"All processes seemed to be a little clearer and more intense during rotation to the right." (P)

"All processes were less clear and less durable this time." (Rotation to the left.) (K)

(e) <u>The period from the application of the brake to the inception of after-nystagmus</u>. The most startling experience resulting from rotation occurs during this period. At first the period is the most upsetting and ordinarily it is responsible for the production of nausea. There is a shift in the pressure at the back of the head, a decided change in the quality of the pressure about the buttocks, and the extraneous visual and tactual processes drop out. A painfully intense kinaesthesis appears localized about the eyes and then suddenly gives way to a series of rapid fluctuations similar in intensity (although more rapid) to those described above.

"The rhythmic appearance of kinaesthesis in the eyes does not appear until stopping has been completed and comes as a climax to that long intense process which starts just as stopping starts and which carries the meaning of the deflection of the eyes in the direction of rotation. The feeling of rotation in the opposite direction and the jumping of the visual field does not begin until this rhythmic kinaesthesis begins." (P)

"A very distinct change in eye-kinaesthesis was felt as stopping began. The eyes were directed toward the side opposite to rotation. They gradually and involuntarily moved over to the extreme opposite and then began the jerking movements. The shift in the kinaesthetic processes about the face and neck was very clear this time." (K)

"Just as rotation stopped there was intense kinaesthesis from the eyes, as if they were being pulled in the direction of rotation and, just as

stopping was complete, the kinaesthesis reached its maximal clearness and intensity, becoming almost painful, and then (as the after-nystagmus began) it gave way to a rhythmic variation in intensity." (L)

The intense kinaesthesis carries with it the meaning of movement of the eyes in the direction of the preceding rotation. Even when ocular kinaesthesis has about disappeared, this one process remains. The perception of rotation in the reverse direction never begins until it gives way to the rhythmic nystagmus movements. The most outstanding fact is the total reorganization that occurs in the musculature of the body. There is a sudden shift in these processes, the more intense processes giving way to a feeling of relief or of release and other muscles are localized as the source of intense pressure.

"The stopping period is full of kinaesthetic pulls and tensions and pressures localized mainly in the eyes and in the neck." (P)

"I caught the shift in the kinaesthetic set during the stopping period very clearly this time. The kinaesthesis during actual rotation was not intense, but was clear, and then, just as rotation stopped, there was a kind of mental pause followed by a shift in the locus of pressure. It seemed to go to the other side of the body, especially in the arms and the shoulders." (K)

"The change which takes place during stopping is more than a resetting. It is like a kinaesthetic and organic shifting as if some change took place in the position of the organs or substance internal to the skin and muscles. Sometimes this change is clear and sometimes it can be reported only as something different,-a kind of organic and kinaesthetic background which seems to change tint-value, as it were. Sometimes 'welling' and pressure are distinguishable; and then again analysis is baffled.: (P)

This shift or change in locus is as temporary as are the other effects of rotation, and soon under repetition, the kinaesthesis in the eyes is the only clear process left. The pressure in the head is very apt to increase temporarily. The eyes are opened as soon as rotation ceases and the whole effect of rotation counter to the real rotation is carried to the field of vision. The description of the filed of vision we have found to make up a large part of previous descriptions. If the eyes remain closed, the kinaesthetic processes about the eyes and the fast disappearing kinaesthetic and organic processes in the body at large carry the entire meaning of rotation. After

much practice, the complexity of the stopping period becomes less, but it is the last complex to give way.

(f) The period from the appearance to the disappearance of the after-nystagmus. The rhythmic kinaesthesis from the eye, which begins as soon as rotation comes to a full stop, continues in the initial turnings for some 20-25 sec. In fact, it is the only thing that is peculiar to this period. The pulls about the eyes are almost painful at first and absolutely uncontrollable. Even after some practice, when a subject has learned to control himself during actual rotation, the confusion persists during this throbbing movement of the eyes when the individual comes to rest. In some cases it carries, for a time, the perception of rotation in the opposite direction; but ordinarily there is only a fluency or a jumpiness of the visual field in a plane corresponding to the plane of rotation. If the eyes are kept closed, the perception of rotation is always present. The kinaesthesis from the arms and shoulders, which may be very intense at first, persists for a few seconds; but that from the neck and face usually continues on with about the same clearness. There are no organic processes peculiar to this period. Whatever is present is but the persistence of sensations set up during the actual rotation. The kinaesthesis about the eyes grows less and less and it finally disappears. The jumpiness of the visual field disappears at the same time.

"The visual field jumps no longer. It is a little blurry and confused for a moment and then clears up suddenly about the same time as the general release in tension is felt about the face and eyes." (P)

(g) The period from the end of the after-nystagmus to the beginning of the next turn. We have found that the pressure from the head and from the upper part of the nose continues almost unabated during the course of the after-nystagmus. Following the last eye-movement there is a period of a few seconds in which these processes continue and then suddenly there is a complete relaxation of the tenseness about the face, the jaws, the eyes, and in the

upper part of the neck. Coincidentally there comes a peculiar and unique change in the feelings about the nead. For example:

"I paid particular attention to the after-period this time. There is a great deal of kinaesthesis,-much more than I had supposed,-about the face, and the release of the tension was very marked. The pressure in the head which began about the second turn and continued through the nystagmus period, took a decided change. There was a clear and decided decrease in pressure as though something had given away lower down and the level of pressure had suddenly fallen as the level of water falls when an opening is made at the bottom of a dish. The disappearance of pressure in the nose left the usual 'raw' feeling." (P)

"The pressure in the head begins about the second rotation. It is quite intense during the stopping period and then, a few seconds after nystagmus, there is a general release of tension all about the face and a lowering of the level of pressure in the nose which leaves a salty 'raw' feeling. The whole experience is of something falling down deep within the brain and neck, which leaves a kind of fresh coolness as opposed to the former stuffiness."(P)

The change that takes place here, however, it not different from the changes we have found from the first, so far as regards the effect of practice. That is to say, at the end of a series this general lowering of pressure and release of tension drops out. We have even found that the initial pressure itself does not arise.

A similar modification of pressure and tension may be induced at any time, if the position of the head is changed, during the rotation or at any prior time to exactly the "release" which we have described. It is also possible to reestablish in this way the 'vertigo' or 'sensation of swimming.'

"As I bent the head forward, there was a distinct change in pressure, the pressure disappearing as well as the kinaesthesis about the face and neck, save in the eyes where there was that characteristic fleeting hazy filmy kind of pull in all directions as if the eyes didn't know where to go. This all gave a feeling of light-headedness which is almost like vertigo. As the pressure leaves the head and neck region, the head seems wobbly and lightly 'propped.' It is more of an effort to keep the head in one position than to move it." (P)

"Felt the same lightness in the head again after changing the position of the head following rotation. The 'swimming' seems to result from an absence of the pressure, which is usual up to this time. There is also an absence of kinaesthesis in the neck which leaves the head with a feeling that it can wobble all over. There is also a peculiar kinaesthesis about the eyes, as if they were going to move in all directions at once. The visual field looks blurry for a moment, like the gravel behind a fast moving train." (P)

"The feeling of lightness and of dizziness, after rotation is

over, is marked mainly by the absence of pressure in the head and nose but with the presence of a strange kind about the eyes, as if the eyes were trying to move in all directions at once and the result is a kind of blankness or greyness of the visual field. The visual field looks as it does during the onset of nausea or after one has suddenly arisen." (K)

"As I bent head forward this time I felt a kind of creepy coolness arising internally, deep in the chest, moving rapidly through the neck to the brain and then a darkening of the visual field and a sense of confusion and light-headedness." (N)

All of these things seem to mark the final cessation of vestibular excitation whatever it may have been. Whenever the "release" described takes place, the subject is ready to change his position or to be rotated again without expecting any of the previous disturbances to carry over. Furthermore, the subject usually takes at this time a deep breath,-the first since rotation began.

(h) <u>The period following the completion of the day's series</u>. After the first few days' practice, subjects reported that it was several hours before they completely recovered from the effects of rotation. This is natural in the case of those subjects who became nauseated, for such a severe organic disturbance could not help but affect the organism for some time. Interest lies, however, in the case of those individuals who were not nauseated and who, nevertheless, reported that they felt as if they had been engaged in hard manual labor. Some felt as if they had just lifted a heavy weight; others as if they had run up a long flight of stairs, and still others as if they had recovered from sickness and were still weak. The reference was made by almost all subjects that the feeling was one of fatigue in the whole body and especially in the legs. Occasionally there was a diffuse light-headedness. This effect tended along with the others to become less prominent as the series proceeded.

"The final processes today were about as usual. There is always a kind of draggy pull at the base of the brain which seems gradually to accumulate during the series. There is a tingling of the feet and elsewhere, as if the body had been for some time under tension and strain. These processes

generally last about a half hour. The head seems heavy, as if ready to fall in any direction at any time and there is a tired feeling in the neck. These processes are not nearly so intense or clear, however, as they were early in the experiments." (P)

The foregoing recital confirms our statement that the experience of rotation is exceedingly complex. Evidence has been adduced to show that there is not a new quality which can be called the 'sensation' of rotation. It is proper only to speak of the perception of rotation, the perception resting upon a host of kinaesthetic pressures, pulls and tensions from all over the body, the head, and so on. When all of these events reach a certain degree of complexity they seem to fuse together into what has been called 'vertigo' or 'dizziness'. Our analysis goes to show that neither of these terms refers to a single item; but rather to the state of mind regarded as a whole. As one becomes adjusted to rotation, this total state disappears and the whole course of events suffers disintegration. It is then possible to reinstate the 'swimming' components and so to identify the individual items in the whole group. Finally, we have found that the mental results of rotation behave in the same manner under repetition as do the organic results. That is to say, the processes which we have designated as principal processes tend to decrease in complexity and in intensity and clearness and finally to disappear. The accessory processes, on the other hand, tend to increase in clearness and so to carry the perception of rotatory movement.

That there is a decided decrease in all of these effects may be further deduced from Table I. It will be seen that, whereas the processes directly dependent upon rotation decrease in number as a series progresses, the extraneous processes actually increase in number, a result in accordance with the introspective reports that the perception of rotation comes to be carried almost entirely by means of these processes after long practice in turning. Furthermore, upon examining Figure 1 it will be ob-

TABLE I

MENTAL QUALITIES GROUPS OF 50 PERIODS		TENDINOUS STRAIN 1	2	3	4	5	6	MUSCULAR PRESSURE 1	2	3	4	5	6	FATIGUE 1	2	3	4	5	6
KINAESTHESIS REFERRED TO	Eyes	45	41	23	15	14	8	47	40	32	16	11	5	11	7	3	0	0	0
	Face	40	31	18	12	7	7	49	31	23	17	8	2						
	Neck	46	45	21	18	14	11	45	36	27	13	7	1	35	16	11	10	7	1
	Arms	47	31	19	18	12	3	49	30	22	17	6	4						
	Back	32	24	14	7	4	1	41	33	19	4	0	0						
	Legs	30	19	12	6	5	3	27	16	4	0	0	0	13	6	3	0	0	0
	Shoulders	27	23	7	2	1	0	20	17	6	1	0	0						
	Chest	31	15	3	0	0	0	45	32	19	11	6	6						

IMAGINAL PROCESSES REFERRED TO						
VISION	5	1	0	1	0	0
TOUCH	3	8	3	0	0	0
KINAESTHESIS	?	?	?			
SMELL	10	4	0	0	0	0

MENTAL QUALITIES		COLD AND WARMTH						PRESSURE						PAIN + PRESSURE						"WELLING" PRESSURE					
ORGANIC AND VASCULAR PROCESSES REFERRED TO	Anus							—	8	2	0	0	0												
	Bowels	16	3	COLD 0	0	0	0	41	16	3	0	0	0												
	Stomach	18	2	WARMTH 0	0	0	0	47	12	2	0	0	0												
	Diaphragm	6	2	WARMTH 0	0	0	0																		
	Chest							27	18	14	7	6	0							25	17	11	10	4	0
	Esophagus																			31	16	5	3	3	1
	Neck																			42	12	14	11	3	2
	Head	4	2	WARMTH 6	2	2	1							19	14	11	7	6	6	49	37	31	23	13	10
	Nose													16	12	7	6	6	4	45	29	21	18	16	12
	Skin	COLD AND WARMTH 32	22	10	0	0	0																		

EXTRANEOUS QUALITIES						
Gustatory	6	2	0	0	0	0
Auditory	2	3	8	10	17	23
Visual	13	10	11	15	14	16
Tactual	8	10	17	23	27	33

Distribution during groups of 50 rotation-periods of the various mental processes aroused by rotation.

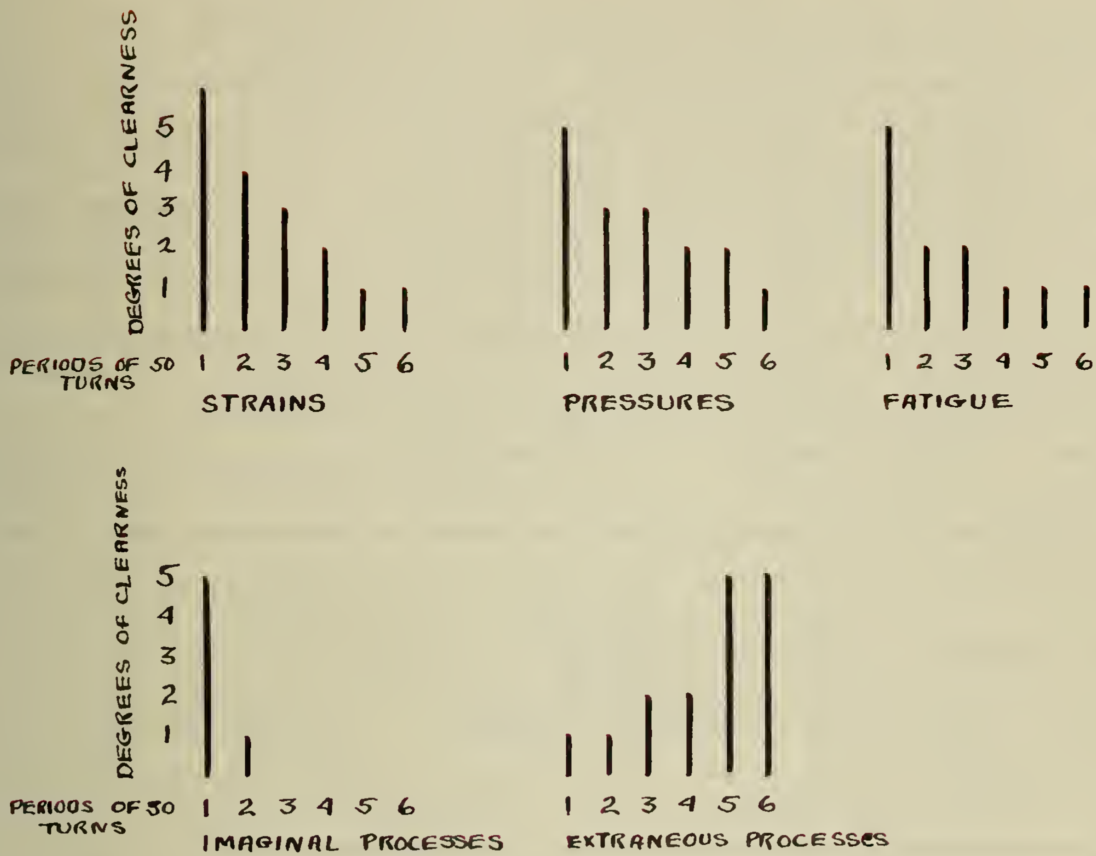

Figure 1. Showing the relative clearness of various processes during the course of trials given to subject P

served that the clearness of the essential processes likewise decreases whereas the clearness of the extraneous processes increases. In a similar schematic way, it could be demonstrated from introspective reports that the intensity and duration of both of these groups decrease and increase respectively. We have already referred to the fact that, toward the end of the series, the kinaesthetic processes appeared only after the fourth and fifth rotations and we have also at hand amply evidence of the reduction in duration.

C. THE DIRECTION OF ATTENTION. The effect of changing the direction of attention was demonstrated in the following manner. Two subjects, I and J, were instructed to regard as attentively as possible a definite fixation point on alternate trials. During the remaining trials they were given a problem in 'mental' multiplication to solve while looking passively, only, at the point of fixation.[1] In these experiments it was thought that this alternation of the conditions might confirm or condemn the otologist's assertions that whatever decrease takes place is the result of "voluntary gaze-fixing."[2] It can be seen from Table II that the effect of holding the

TABLE II

	Subj. I			Subj J		
Fixation	T	No.	A.M.	T	No.	A.M.
Av. 1st 50 trials	14.8	23.4	11.1	15.9	35.4	10.9
Av. last 50 "	12.2	18.5	10.7	12.7	31.2	8.5
Decrease	2.6	4.9	0.5	3.2	4.2	2.4
Problem						
Av. 1st 50 trials	13.2	18.3	10.3	12.3	26.0	11.2
Av. last 50 "	9.0	10.4	8.9	9.9	20.5	8.8
Decrease	4.2	7.9	1.4	2.4	5.5	2.4

1. The problems were chosen experimentally and were designed to keep the subject busy as long as the after-nystagmus continued. Care was taken, however, not to make the problems so difficult as to confuse the subject and thus to defeat the purpose of the test.
2. See Manual Medical Research Laboratory, Wash. D.C., 1918. Also J. Amer. Med. ASS., 1919, 72, 780; The Laryngoscope, 1920, 30, 22-25.

fixation mark tends to leave at a higher level the duration of the nystagmus, the number of movements, and the time of apparent movement. As regards the amount of decrease, it appears that for subject I, the decrease during the series (compare first and last values) is greater in the problem series than in the steady fixation series. The problem series gives less decrease, however, in J's case for the distraction of the problem. It is not clear, however, just what is involved in attending to a fixation point. From introspective accounts it was discovered that the kind of attention present in this case was accompanied by a great deal of kinaesthesis from the face, especially from the forehead, neck and eyes. The subjects "stared" with all their might in an effort to overcome the confusion resulting from the nystagmus. At any rate, it is not possible to attribute the decrease in the intensity of the ocular effects of rotation during practice to the trick of "gaze-fixing".

D. PSYCHOPHYSICAL DETERMINATION. The facts we have just presented are further illuminated by the results issuing from a changed mental and bodily determination. The introspective records have already suggested the influence of this mental pre-condition. We have seen that the determination induced by certain imaginal processes profoundly influenced the course of the subsequent processes. We have also seen that, under the influence of the instruction given above, the effects were increased in intensity. Further instructions were now given to the effect that the subject should on some occasions induce the "staring" attitude and on other occasions the resisting attitude of the whole body. In this way it was discovered that the setting of the whole organism against the confusion of rotation served to check the confusion and to shorten the duration of the processes, a result quite contrary to that obtained by merely staring at a fixation mark. For example:

"I tried to inhibit nystagmus this time. Atttitude of resistance

was carried in terms of tension about the legs, buttocks, arms, and back. The whole body was set in resistance. Found that I was quite successful,-success being carried in terms of greatly reduced confusion." (P)

During a group of thirty trials subject P's averages for trials involving no setting were 20.1 8.5 20.6 and for trials involving the resistance of the whole body 10.4 5.4 10.4 It seems, then, that such a psychophysical preadjustment, while not accomplishing much early in a series, may later reduce very materially the time of nystagmus, the number of movements, and the time of the apparent movements.[1]

E. VISUAL FACTORS. Attention has frequently been called to the effect of changes in visual factors on the appearance of nystagmus. For instance, Bárány say that nystagmus may be completely inhibited by looking fixedly in the direction of the quick component of the movement. We are here interested, however, not in the matter of voluntary inhibition, but in the ways in which the appearance of the mental effects of rotation may be modified by changes in the visual conditions.

(1) Character of the visual field during rotation. We shall first discuss the effect of the character of the visual field during rotation. Subject M was rotated in the regular manner, but on alternate trials he was blind-folded during the period of rotation while during the remainder of the trials his eyes were left open. It was found (See Table III) that the

TABLE III

	Closed			Open		
Trials	T	No.	A.M.	T	No.	A.M.
1st 50	17.6	31.0	15.9	14.5	21.3	13.2
2nd 50	14.2	23.0	13.9	11.4	12.6	10.6
3rd 50	10.8	17.4	10.8	6.7	7.5	6.9
4th 50	9.1	12.3	9.2	4.6	4.4	4.6

1. This sort of decrease is not to be confused, however, with the decrease that issues directly from practice. A subject may reduce nystagmus considerably by "gazing" but the decrease is momentary only.

nystagmus was greatly decreased in time when the eyes were kept open during rotation and that the amplitude of the movements was smaller. Subject M also reported a greatly decreased sense of dizziness when the eyes were open and during the early part of the series the nausea and other organic disturbances were less intense.

(2) In the second place, we shall discuss the effect of the character of the visual field after rotation, or, in other words, the effect of the mode of fixation. Three variations in the mode of fixation were required of our subjects. These were (a) the effect of near-fixation versus far-fixation, (b) the effect of no fixation, and (c) the effect of lateral fixation. In the first case, the subject was allowed in part of the trials to fixate a point about one hundred feet distant, i.e., well beyond the maximal point for parallel axes, and in the other part of the trials the subject fixated a point six inches distant. Under these conditions, it was found that the time of nystagmus, the number of eye-movements, and the time of apparent movement were approximatley twice as great during far-fixation than during near-fixation. (See Table IV.) This difference appears not only in the groups of five-day periods

TABLE IV

	Far fixation			Near fixation		
Trials	Time	No.	App. Mvt.	Time	No.	App. Mvt.
1st 50	15.8	30.5	13.8	7.9	12.1	7.5
2nd 50	10.1	18.9	9.7	5.7	7.7	5.5
3rd 50	5.6	9.0	5.6	2.9	3.5	2.9
4th 50	3.2	4.7	3.2	1.2	1.2	1.2

but also for the averages of the whole series. The most pronounced difference is found in the number of the eye-movements made.

As regards non-fixation, three variations in method were used. In the first case, subjects R and S were rotated as usual, but their after-

nystagmus was observed while they were wearing lenses of 20 dioptres. In the second group, subjects Q and T used lenses, but they were also stopped facing a homogeneous surface of grey paper. In the third case, subjects D and G were rotated as usual, but the nystagmus time was obtained by observing from the side as a piece of cardboard 3 x 6 in. was held before the eyes of the subjects. In all these cases, the effort was made to eliminate, so far as possible, all fixation. The results are so nearly alike that they will be treated together in Table V.

An examination of the table shows that the initial values are much larger than in the case of 'normal' vision. In fact, the average initial time of nystagmus (not including subjects G and V who took this series after a long series under other conditions) for these subjects is 41.0 sec. which is over twice as large as the initial values for usual fixation. In other words, this value is as much larger than the value obtained under normal conditions as the value obtained under normal conditions is larger than that obtained under near-fixation (at 6 in.). The initial values obtained from subjects G and V are pertinent. Both of these subjects had had long previous practice. Subject G, *e.g.*, had lost all ocular movement under the conditions then obtaining. Under the new conditions, where fixation was eliminated, his nystagmus time was 18.8 sec. The same is true of subject D. These facts suggest that essentially different conditions obtain during the wearing of lenses, and also that the effect of lenses is to increase very markedly the time of nystagmus and the number of apparent movements. It is not at all improbable that 'normal' nystagmus movements are gotten only when fixation is eliminated; or, in other words, any kind of fixation is possible only when the ocular muscles are being innervated from other sources than the vestibular tracts. Vestibular excitations are superimposed, therefore,

TABLE 5

Trial	TIME OF NYSTAGMUS Subjects								NUMBER OF MOVEMENTS Subjects							
	Q	Q CON	R	R CON	S	T	D	D CON.	Q	Q CON.	R	R CON	S	T	D	D CON
1	45.9	18.2	35.0	22.2	33.0	50.0	18.0	1.9	45.4	24.5	37.2	17.0	53.7	88.5	13.5	1.9
2	44.3	20.1	35.9	17.4	32.0	41.1	17.8	1.2	47.8	26.5	38.6	12.7	52.1	89.4	16.9	1.2
3	44.6	18.2	33.0	16.1	31.0	39.0	17.3	0.4	46.7	25.3	29.1	12.8	50.2	83.2	14.7	0.4
4	43.4	19.0	39.6	12.0	36.2	39.1	14.0	0.0	49.6	26.5	32.6	7.2	58.3	73.7	9.7	0.0
5	35.1	18.2	34.2	6.0	29.8	40.5	14.5	0.0	43.1	24.8	34.5	4.5	48.9	76.5	12.2	0.0
Av.	42.6	18.8	35.6	14.7	32.4	41.9	16.3		46.5	25.5	34.4	10.8	52.6	80.3	13.4	
6	29.5	18.9	35.0		25.4	31.4	9.3		37.2	26.3	29.9		45.0	64.1	7.8	
7	31.3	19.7	36.5		28.1	31.8	11.3		34.7	24.6	16.0		50.7	63.9	8.5	
8	26.2	19.0	29.5		31.3	35.0	8.6		27.5	24.9	23.4		48.0	65.5	8.1	
9	32.6	18.3	31.2		33.2	38.7	10.0		35.9	25.1	27.8		49.8	69.4	8.8	
10	27.7	16.1	32.6		27.2	27.8	9.5		39.5	22.5	19.4		43.1	62.9	6.7	
Av	29.4	18.4	33.0		29.0	33.0	9.7		35.0	24.7	23.3		47.3	65.2	7.9	
11	20.9		32.3		26.2	30.1	10.8		27.4		28.6		43.8	60.9	7.6	
12	21.7		26.6		25.4	27.6	10.9		32.0		17.1		39.3	57.5	10.6	
13	19.9		25.4		25.2	25.8	8.1		24.7		22.0		37.9	45.0	7.5	
14	20.8		29.1		20.7	21.8	6.2		29.3		24.1		32.9	51.2	4.8	
15	19.9		27.3		17.8	24.8	7.5		26.8		24.7		25.7	55.8	7.2	
Av	20.6		28.1		23.0	26.0	8.7		28.0		23.3		35.9	54.5	7.5	
16	25.6		25.5		17.7	24.8	6.1		29.4		25.5		29.7	52.8	5.3	
17	19.6		24.3		22.1	22.9	4.3		24.0		16.9		34.1	47.8	3.6	
18	21.3		16.2		17.4	25.5	4.1		28.8		10.7		27.8	52.0	4.7	
19	21.3		17.5		16.2	20.4	2.6		27.3		11.9		24.1	43.5	2.7	
20	20.8		20.2		15.3	18.7	3.9		26.4		16.8		22.7	38.1	3.1	
Av	21.7		20.7		17.7	22.5	4.2		27.2		16.3		27.7	46.8	3.9	
Decrease in Sec.	29.8		29.0		17.7	31.3	18.0		22.9		32.7		31.0	50.4	13.5	
Decrease in %	65		83		53	62	100		50		88		58	57	100	

Averages of 10 revolutions (5 to R and 5 to L), the subjects wearing plus 20 lenses.

upon excitations already taking place when a subject is fixating any point whatsoever.

Further examination of Table V makes it evident that the factors which we found to be operative in the decrease under usual conditions also appear here, viz., a large part of the decrease takes place at first, and there are wide individual differences in the rate of decrease and in the initial values. These facts, especially the observation that decrease occurs with practice, even though fixation is eliminated, are again of great significance in view of the contention of certain otologists that the small decrease they found was due to "gaze-fixing" and not to practice.[1]

Finally, we shall discuss the question of lateral fixation. Attention has frequently been called to the fact that if, during rotation, one looks laterally in the direction of rotation the time of nystagmus is greatly increased while to look in the direction opposite to rotation causes a decrease in the time of nystagmus.[2] That is to say, the time of nystagmus is increased if the subject looks in the direction of the quick component of the ocular movements. This is also true during the after-nystagmus. For example, subjects J, W, and D were rotated and so stopped that it would be necessary for them to fixate the prescribed mark out of the corner of the eye. After being rotated to their left they were instructed to look laterally during the period of the after-nystagmus to the right and when rotated to the right they looked, during the after-nystagmus, to the left. In other words, the gaze was directed with the quick componenet of the ocular movements. Under these conditions, it was found that the time of nystagmus was increased although

1. See Fisher and Babcock, J. Amer. Med. Ass., 1918, 72- 780.
2. Fridenberg, P., The non-acoustic functions of the labyrinth, Trans. Amer. Otol Soc., 1908, 11, 181-182. Bárány, R., Untersuchungen über den vom Vestibularapparates des Ohres reflektorisch ausgelösten rhythmischen Nystagmus und seine Begleiterscheinungen, Monat. f. Ohrenhk., 1906, 40 193-297.

the amplitude of the movements was smaller than during direct fixation. Table VI shows the results from these three subjects. The average initial time is 26.7, a value 8.7 sec. larger than the corresponding value for normal conditions. Still more important is the fact that decrease is all values takes place as a result of practice in the same general manner as was found to be the case above. Bárány has suggested that unless the nystagmus is intense it may be entirely concealed by looking straight ahead. That the decrease in nystagmus found above is not, therefore, a result of a temporary concealment due to looking directly ahead but that it is a genuine decrease which takes place even though the conditions of fixation are such as to bring about almost a maximal effect, (we have already pointed out that a maximal effect is probably produced when fixation is entirely eliminated) is indicated by the decrease found during lateral fixation. It was true in these cases that after-nystagmus could be almost if not quite eliminated by looking laterally in the opposite direction; but each of our subjects reported that, at first, the eye seemed to be under an intense strain; later in the series when the intensity of nystagmus had decreased, the strain entirely disappeared.

TABLE VI

	TIME OF NYSTAGMUS					NUMBER OF MOVEMENTS				
	Subjects					Subjects				
TRIAL	W	W CON.	W CON.	D	D CON	W	W CON	W CON	D	D CON.
1	28.0	9.7	8.2	25.9	11.6	71.1	21.0	16.6	46.5	19.6
2	28.7	12.4	7.0	24.7	12.0	74.6	27.4	14.6	44.8	20.0
3	27.0	13.2	6.7	24.3	14.1	72.0	26.4	13.8	43.8	23.2
4	26.8	12.4	5.9	23.8	12.5	52.1	23.7	11.7	44.0	25.5
5	24.0	11.4	5.9	20.1	11.7	50.7	23.6	13.3	41.2	19.3
Av	26.4	11.8	6.7	23.7	12.4	64.1	24.3	14.0	44.0	21.5
6	21.0	11.2	6.3	22.4	10.3	43.1	21.7	14.7	37.9	16.3
7	17.8	12.3	6.1	23.7	9.2	40.1	24.2	12.2	51.2	12.3
8	16.1	12.4	5.1	20.2	10.1	40.6	27.1	9.6	44.5	12.2
9	15.7	13.2	6.3	13.7	7.7	37.1	23.0	12.3	32.9	10.2
10	12.4	10.8	5.2	17.3	8.6	27.3	25.8	11.1	35.0	10.0
Av	16.7	11.9	5.8	19.4	9.2	37.6	25.4	12.0	40.3	12.2
11	13.2	11.3	5.7	17.4	7.7	29.4	27.0	9.3	33.8	7.6
12	14.5	11.2	5.9	13.6	8.8	33.7	23.4	10.8	38.5	9.5
13	15.2	9.7	4.9	16.9	6.1	32.1	24.9	10.1	35.3	6.8
14	15.6	10.7	4.8	17.3	7.1	33.4	25.2	9.1	39.7	7.7
15	13.7	11.3	4.1	12.0	6.2	28.9	26.6	7.6	23.2	6.1
Av	14.4	10.8	5.0	15.4	7.2	31.5	27.5	9.4	34.1	7.5
16	15.8	10.8		13.4	5.8	31.8	20.9		26.7	5.6
17	15.6	8.5		13.7	2.9	33.6	18.5		23.9	2.3
18	11.7	9.2		13.0	1.0	24.8	21.5		22.8	0.9
19	13.5	9.6		12.2	0.0	28.6	21.4		21.6	0.0
20	13.5	8.2		11.6	0.0	29.9	17.5		20.1	0.0
Av.	14.0	9.3		12.8	1.9	29.7	19.9		23.0	1.8
DECREASE IN SEC.			23.9		25.9			63.5		46.5
DECREASE IN %			85		100			89		100

Averages of 10 revolutions (5 to R and 5 to L) both subjects gazing laterally at the fixation point.

CHAPTER IV

CONCLUSION

We come now to a concluding statement of the facts issuing from our experiments and from our introspective analyses. We have found the experience of dizziness or vertigo to be made up of a large number of processes the most prominent of which are (1) kinaesthesis from the eyes and neck and in the arms, (2) pressure from the region of the abdominal viscera, the chest and head, and (3) certain vascular processes which supply an obscure background and which give to the whole experience a characteristic shading. We have found, moreover, that the whole experience of dizziness becomes less complex and less intensive under periodic repetition. Nowhere have we been able to discover a process which could be called a 'sensation of rotation' or a 'sensation of movement.' As a result of our analysis, we are justified not only in saying that all of the mental processes resulting from rotation may be modified by a variety of physical and physiological factors, but also that certain mental factors modify all of the results of rotation, both organic and mental. That is to say, the organic and mental effects of rotation are an integrated group of events highly sensitive in their appearance and duration to a wide variety of mental conditions. These conditions we have found to be (a) the direction of attention, (b) a psychophysical determination, (c) the character of the visual field, and (d) the mode of fixation.

Vita

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